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REPORT OF THE UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON APPLICATIONS OF SPACE TECHNIQUES TO PREVENT AND COMBAT NATURAL DISASTERS, ORGANIZED IN COOPERATION WITH THE GOVERNMENT OF ZIMBABWE

(Harare, 22-26 May 1995)

CONTENTS

	Paragraphs	*Page*
INTRODUCTION	1-10	2
A. Background and objectives	1-5	2
B. Organization and programme of the Workshop	6-10	2
I. OBSERVATIONS AND RECOMMENDATIONS OF THE WORKSHOP	11-14	3
A. Observations of the Workshop	11-13	3
B. Recommendations of the Workshop	14	3
II. SUMMARY OF PRESENTATIONS	15-78	4
A. The role of the International Decade for Natural Disaster Reduction and the contribution of space technology	21-24	4
B. Regional disaster-related problems and projects	25-33	5
C. Current and future possibilities for satellite communications	34-58	6
D. Use of data from remote sensing satellites	59-74	10
E. A global monitoring and warning satellite system	75-78	13

Annexes

I.	Programme of the Workshop	14
II.	Working paper on data supply (Group A)	17
III.	Working paper on information generation (Group B)	20
IV.	Working paper on decision process (Group C)	22
V.	Working paper on implementation/execution (Group D)	24

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INTRODUCTION

A. Background and objectives

1. On 10 December 1982, the General Assembly adopted resolution 37/90 in which it endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space. In that resolution, the Assembly decided, *inter alia*, that the United Nations Programme on Space Applications should disseminate, through panel meetings and seminars, information on new and advanced technology and applications, with emphasis on their relevance and implications for developing countries.

2. The United Nations/European Space Agency Workshop on Applications of Space Techniques to Prevent and Combat Natural Disasters was one of the activities of the Programme for 1995 that were endorsed by the General Assembly in its resolution 49/34 of 9 December 1994. The Workshop was organized in cooperation with the Government of Zimbabwe. It was hosted by the Environment and Remote Sensing Institute (ERSI) and held at Harare, from 22 to 26 May 1995, for participants from developing countries of the region covered by the Economic Commission for Africa (ECA).

3. The objectives of the Workshop were (a) to expose the participants, particularly managers of emergency response agencies, to ways and means of utilizing space technology (remote sensing, satellite meteorology, satellite communications, positioning by satellites) to prevent or mitigate the effects of natural disasters; and (b) to address the development of databases and their use with Geographic Information Systems (GIS) to prevent disasters or to monitor, mitigate and redress the effects of disasters when they occur.

4. The presentations to the Workshop covered the use of remote sensing, satellite meteorology, satellite positioning systems and satellite communications and how they could be used, separately or collectively, to prevent disasters or to forecast, monitor and mitigate the effects of severe weather phenomena, such as flooding, desertification and drought. The presentations also addressed the extent to which the same technologies could mitigate the effects of earthquakes and volcanic eruptions. The Workshop concluded with discussions on the needs of the emergency response services, the capabilities of space technology to satisfy those needs and the actions that would be necessary in the short- and medium-term to take advantage of those capabilities.

5. The present report, which covers the background, objectives and organization of the Workshop, the observations and recommendations made by the participants, as well as a summary of the presentations, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. The participants will report to the appropriate authorities in their own countries.

B. Organization and programme of the Workshop

6. The participants were professionals with several years experience in managerial positions with national and regional emergency response agencies and services. Other participants had several years experience in remote sensing, satellite meteorology and the use of databases such as GIS. Sixty-nine experts from 18 States Members of the United Nations and eight international and regional organizations participated in the Workshop; 44 participants represented 14 developing countries from the ECA region.

7. The Workshop was attended by participants from the following countries and international organizations: Benin, Botswana, Egypt, Ethiopia, Ghana, Kenya, Malawi, Nigeria, South Africa, Sudan, United Republic of Tanzania, Zambia and Zimbabwe. Presentations were made by experts from Ghana, France, Japan, Norway, South Africa, United Republic of Tanzania, United States of America and Zimbabwe; from European Space Agency (ESA), International Federation of Red Cross and Red Crescent Societies (regional delegation for Southern Africa), International Mobile Satellite Organization (Inmarsat), International Telecommunications Satellite Organization (INTELSAT), Food and Agriculture Organization of the United

Nations (FAO), Department of Humanitarian Affairs of the United Nations/International Decade for Natural Disaster Reduction (UNDHA/IDNDR), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations Office for Outer Space Affairs, as well as by a representative of the Globalstar satellite communications company.

8. Funds allocated by the United Nations and ESA were used to defray the air travel and per diem expenses of 14 participants from 11 developing countries of the ECA region. The Government of Zimbabwe, through ERSI, provided the conference facilities and the Government also provided local transportation for all participants in the Workshop.

9. Opening addresses were made by Prof. C. J. Chetsanga, Director-General of the Scientific and Industrial Research and Development Centre of Zimbabwe, on behalf of the Government of Zimbabwe, C. Berquist, the representative of ESA, and the Expert on Space Applications, Office for Outer Space Affairs of the United Nations.

10. The programme of the Workshop (annex I), was developed jointly by the United Nations and ESA. The Workshop held plenary and working group meetings. At the latter, the participants discussed the issues related to the use of space technologies to prevent and combat the effects of natural disasters. The working papers of these groups are given in annexes II-V.

I. OBSERVATIONS AND RECOMMENDATIONS OF THE WORKSHOP

A. Observations of the Workshop

11. The critical factors that distinguish natural phenomena from natural disasters are loss of life and property. Certainly, humans cannot prevent the occurrence of natural phenomena such as typhoons, hurricanes, earthquakes and volcanic eruptions. Their disastrous effects, however, can be lessened significantly if well-conceived disaster-response plans and mitigation strategies are in place prior to their occurrence.

12. The Workshop noted that developing countries were particularly subject to natural disasters on a scale that overwhelmed the capacity of the societies concerned to cope with their aftermath. In many cases, just one such destructive episode was sufficient to destroy the social and economic infrastructure, including the communications network. A single major disaster could disrupt the distribution of food and water supplies, medical services, and both the local and international communication links of the stricken communities.

13. The Workshop noted that many of the national and regional emergency response agencies and services were not aware of the full spectrum of applications of space technology. Of particular concern was the lack of awareness of the Earth observing systems that could provide essential data for the prevention of disasters or for the mitigation and relief of their effects. To a lesser degree, the same observations applied to satellite communications, particularly regarding recent developments in mobile communications. In the case of natural disasters, such technology could restore communications with the local headquarters for rescue and relief operations as well as with the outside world.

B. Recommendations of the Workshop

14. During the last session of the Workshop, the participants defined four categories of disaster-related topics that needed to be addressed: data supply, information generation, decision-making and implementation/execution. To develop outlines of recommendations that could be useful in disaster-related activities, the participants assigned themselves to one of the above groups according to their professional background.

II. SUMMARY OF PRESENTATIONS

15. In recent years, the frequency and magnitude of major disasters, whether of a natural, technological or ecological origin, have made the world community aware of the immense loss of human life and economic resources that are regularly caused by such calamities. Particularly hard hit are developing countries, for which the magnitude of disasters frequently outstrips the ability of the society to cope with them. It was stated that this was due to the fact that 95 per cent of all disasters occurred in developing countries.

16. Over the past 20 years, the frequency and severity of natural disasters have increased. Over this timespan, 3 million people have been killed and 1 billion have been affected by natural disasters. Hardly a week goes by without a major disaster. Since the earthquake in Kobe, Japan, in January 1995, there have been over 20 large disasters reported in Africa, Asia and Latin America. Civil strife, such as the recent events in Rwanda, also affects people, the economy and the infrastructure in ways similar to a very large natural disaster.

17. To date, relief continues to be the main form of disaster management. Approximately 95 per cent of all resources spent on disaster-related activities are for relief and recovery operations. Nevertheless, disasters can be reduced if adequate research and proven prevention, preparedness and emergency measures are taken. The effects of disasters can only be reduced through the deployment of the very best systems and knowledge, and following well-prepared overall national and regional contingency plans.

18. A single hazardous event can destroy the social and economic infrastructure, including communications systems, that may have taken years to develop and upon whose vitality local and national economies depend. Even in normal times, particularly in developing countries, the capacities of these infrastructures are often strained to manage even the most basic social and economic development programmes, and a single disaster can severely disrupt the community lifelines that provide food distribution, water supplies, health-care services, waste disposal and communications locally and with the rest of the world.

19. In order to realize their fullest potential, developing countries need a sustained period of social and economic growth. Major impediments to sustained growth are disasters, which often result in an affected country shifting its economic policies to sustain the energy required to cope with disaster response and subsequent reconstruction. These shifts can intensify a country's financial imbalances and deplete available resources.

20. In many cases such a situation can be prevented. Frequently, the difference between saving and losing lives and property is an effective warning of an impending disaster. Timely warning of a major natural hazard can reduce its consequences: at least, people may have enough time to save their lives; at most, they have an opportunity to relocate or otherwise protect their property.

A. The role of the International Decade for Natural Disaster Reduction and the contribution of space technology

21. The International Decade for Natural Disaster Reduction (IDNDR) 1990-1999 operates within the framework of the Department of Humanitarian Affairs of the United Nations and was proclaimed by the General Assembly in its resolution 44/236 of 22 December 1989 with the objective of reducing, by concerted international action, especially in developing countries, the loss of life, property damage and social and economic disruption caused by natural disasters such as earthquakes, windstorms, tsunamis, floods, landslides, volcanic eruptions, wildfires, infestations of grasshoppers and locusts, droughts and desertification, and other calamities of natural origin.

22. The IDNDR secretariat recognizes that space technologies, including remote sensing, global positioning and satellite communications systems, offer disaster managers valuable tools that can be used to prepare for,

mitigate and, in some cases, prevent the effects of disasters. Appropriate applications of space technologies can also be used to respond more effectively to needs resulting from disasters.

23. IDNDR provides an international mechanism to focus attention on the benefits of applying these and other technologies. Importantly, it directs the disaster management community beyond the issue of simply using state-of-the-art space technologies in disaster relief and early warning because it promotes a recognition that the national infrastructures that make possible these applications must be encouraged and supported.

24. Because of the typically high infrastructure investment that is required for constructing and managing space-based programmes, national, and local, systems are out of reach for most of the countries hardest hit by natural disasters. Therefore, the IDNDR secretariat is seeking ways of encouraging the development of cooperative approaches for sharing space-based resources. Although the sovereignty of the country affected by the disaster should be recognized, the planning and administration of this process must also include recipient countries. The development of an autonomous basic research capability in scientific and technical disciplines, including space-related fields, should be a main goal as advocated in ongoing activities within the United Nations, most notably through the Office for Outer Space Affairs. Such capability would promote creative thinking to adapt, modify and create new technologies that could contribute to national development and the reduction of casualties and property damage.

B. Regional disaster-related problems and projects

25. There are many disaster-reduction challenges confronting Southern Africa, the major hazards of concern being drought, epidemics, cyclones and storms, floods and armed conflict. In 1991 and 1992, more than 20 million people in this region were defined as severely drought affected. Drought in this region is also associated with other hazards, such as flash floods and epidemic diarrhoea, including cholera and dysentery. In 1995 there have been flash floods in Botswana, northern Namibia and parts of Southern Africa.

26. Unfortunately, for Southern Africa, cholera and dysentery constitute a serious threat. In 1993, more than 50,000 cases of cholera and up to 73,000 cases of shizella dysentery were recorded in five Southern African countries. In 1994, more than 171,000 cases of dysentery were reported for Malawi, Mozambique and Zimbabwe, claiming nearly 600 lives.

27. Irrespective of whether the hazard is meteorological, such as a cyclone, epidemiological, such as a cholera outbreak, or hydrological, such as a drought, Southern Africa's most disaster prone communities are those already vulnerable due to poverty, isolation, and dependence on degraded land and location in crowded informal settlements. Disaster reduction is synonymous with lowering this vulnerability, a daunting challenge facing Southern African governments during a time of fiscal restraint and economic structural adjustment.

28. In Zimbabwe, remote sensing and GIS projects started as small disjointed donor-funded projects that were designed to test the applicability of the technology in different fields of application. The earliest pilot projects were in the fields of land-use planning and vegetation monitoring. At that time, satellite data came in as computer compatible tapes in the diplomatic baggage of the technical personnel from donor countries. In 1987, ERSI was inaugurated as a service centre to spearhead advances in the use of remote sensing and GIS technology. The facility was set up as a joint project between the governments of Zimbabwe and Germany.

29. With time, it was realized that there was a need to coordinate the projects that were being developed all over the country in order to take advantage of already existing data sets, hardware and software to rationalize human and technical resources. The research council of Zimbabwe established a subcommittee on remote sensing in an attempt to coordinate remote sensing activities in the country. A working group on GIS was also established. ERSI is presently involved in capacity building, both in-house and within the existing and new-user community.

30. The limited success in the control of land degradation and desertification may be attributed to a number of factors that include lack of data relating to the spatial and temporal dimensions of the problem. High-resolution satellite remote sensing data is suitable for the collection of spatial data for broad planning and monitoring. The possibility of assessing in particular the spatial and temporal dimensions of the problem of desertification is enhanced.

31. In Ghana, the most extensive use of high resolution satellite data to map current land use and cover for the country is currently taking place within the Remote Sensing Applications Unit of the Department of Geography, University of Ghana. The project is using satellite image data to map land use at the scale of 1:250,000 as a part of the Environmental Information Systems Development component of the Ghana Environmental Resources Management Project (GERMP). GERMP is part of the implementation of the Environmental Action Plan prepared by the Ghana Environmental Protection Agency (EPA). The other sets of data to be produced include topography, meteorology, soil suitability and land ownership. These databases are expected to be available by 1997 to be organized into an environmental database that will be developed and shared in an environmental information systems network. The Desertification Control Unit within EPA will be expected to use the maps to assess the medium-term and longer term effects of the many environmental and land-use programmes and projects currently being undertaken in all the ecological zones of the country, but particularly in the northern savannahs.

32. In the United Republic of Tanzania, recurring fire hazards, whether natural or human-made, have swept the vegetation off of various areas of the country except in the very wet rain forest. Deliberate or accidental fires have had disastrous effects on the ecology and economy of the areas concerned. In developing countries such as the United Republic of Tanzania, however, the deliberate burning of vegetation continues to aid farming and hunting of game in forested areas. The impact of fire on forest land can be detected by using remote sensing techniques and GIS. With respect to technology management, the latest GIS programs, IDRISI and TOSCA, have already been introduced in the United Republic of Tanzania through the United Nations Institute for Training and Research (UNITAR). It may be concluded that remote sensing images are a useful database source when used in conjunction with sufficient ground surveys in combating forest fires.

33. In 1992 a project was initiated in South Africa to develop a monitoring system for drought and vegetation conditions. This operation requires information at regular intervals at a national level. The advanced very high resolution radiometer (AVHRR) instrument carried by satellites of the National Oceanographic and Atmospheric Administration (NOAA) of the United States of America is the only commercial data source available to satisfy the needs and requirements of a fully operational exercise of this magnitude. Unique properties, such as daily coverage of a large area, facilitate regular inventories to be made of natural events on a national scale. Daily NOAA/AVHRR satellite images are used as a primary input source to produce monthly inventories of the whole country in the form of vegetation index maps. Analyses and comparisons of current and historical maps enable the objective assessment of the effect of prevailing or emerging drought conditions in a timely fashion. With proper calibration and the establishment of a continuous long-term database, this information will become a strong tool for decision makers and land managers.

C. Current and future possibilities for satellite communications

34. Traditional terrestrial telecommunications, particularly in remote areas of disaster-prone countries, have been costly to install, difficult to repair and vulnerable to damage. Accordingly, such systems have been virtually useless in areas where geography or climate have inhibited their installation and maintenance, and thus have been of limited value to disaster managers. Fixed satellite services, though useful in disaster planning and warning, have been of relatively limited effectiveness in disaster response, principally because of the need for large receiving and transmitting antennas and their associated high power requirement, and vulnerability to effects of disasters.

35. Mobile satellite services have been one of the most recent and dynamic communications technologies available to disaster managers. This low-cost communication capability has proven, even in the relatively short time of its commercial availability, to offer dramatic results in relief efforts that have not been possible before. Furthermore, as a complement to remote sensing and the global positioning system (GPS), space technology and GIS information management applications, mobile satellite services have the capability to dramatically improve risk assessment, disaster preparedness, early warning, and onset and post-disaster relief operations. These services are now available to areas previously considered inaccessible because of their location, terrain, weather or demography.

36. In the future, global mobile communications systems, such as the many planned low Earth orbit (LEO) systems, will greatly enhance the disaster mitigation efforts of relief organizations. Providing truly global personal communications, these systems, including the proposed Globalstar system, will provide a wide array of opportunities for information exchange through voice, digital data transfer and paging. An alternate, or back-up capability, will also be provided to ground-based emergency alerting and local services for immediate reporting and request for assistance capabilities in natural disasters, accidents and other emergencies as well as aviation and marine navigation.

37. A few years ago the mobile satellite technologies that had for so long been employed on an experimental basis were only then beginning to be used in institutions. Mobile satellite services offering land, aeronautical and maritime mobile communications are now being used regularly in disaster applications and will be used increasingly throughout the 1990s and beyond.

38. The growing awareness and consideration of these societal issues together with advances in spaceborne technology mean that effective, affordable and global mobile satellite communications and remote sensing capabilities that should significantly reduce the devastating effects of natural disasters should soon be implemented.

39. Because mobile satellite communications systems are independent of the local telecommunications infrastructure, they are not affected by natural disasters and they are frequently the only means of communications to and from a stricken area. The Inmarsat satellite system can be used in all phases of dealing with natural disasters, monitoring and prediction, warning, and early intervention and emergency operations, and can also provide communications support for rehabilitation and reconstruction after a disaster strikes.

40. The 1994 IDNDR World Conference on Natural Disaster Reduction, held at Yokohama, Japan, identified telecommunications and information systems as two of the main elements of its "Strategy for a safer world and plan of action", which was subsequently endorsed by the General Assembly in its resolution 49/22 B of 20 December 1994. The Tampere Conference in 1991, as well as the World Conference on Telecommunications Development of the International Telecommunication Union (ITU), held at Buenos Aires in 1994 and the subsequent Kyoto Plenipotentiary Conference, endorsed the principle of maximum use of existing satellite and terrestrial telecommunications systems for disaster mitigation. This includes the preparation of national disaster emergency and contingency plans, establishment of pools of expertise and equipment for such purposes, inclusion of emergency telecommunications systems in national development plans and revision of national regulatory policies to allow effective deployment of telecommunications in disasters and emergencies.

41. National contingency plans can help to minimize the impact of sudden natural disasters, for example by the pre-positioning of emergency supplies and communications equipment, including satellite communications systems, at strategic locations such as government premises and hospitals in areas known to be at risk. As the process of identifying needs and the subsequent funding and deployment of satellite communications systems can take months, such activity has to be started as soon as possible.

42. For slowly developing disasters, such as droughts or famines, a different telecommunications strategy is needed. The impact of disasters on sustainable development has been shown to be very severe. As telecommunications are one of the essential tools for disaster management, the national emergency or disaster management planners need to consider how best to use the available networks and systems during the research and monitoring phase, as well as for contact with established international aid agencies during the relief phase.

43. Preparedness planning for all disasters and emergencies involves national civil defence, emergency response organizations and various government departments. The military is increasingly called on to contribute in this role. The International Committee of the Red Cross and other health organizations also participate. An increasing number of preparations are being conducted on a regional basis. While the levels of technical ability and understanding of technology of local personnel are steadily increasing, the main problem is lack of funds. This, however, can often be overcome by international cooperation or external funding.

44. Monitoring weather and climate has long been an invaluable tool in predicting and combating natural disasters. Inmarsat satellite communications systems help in the gathering and dissemination of meteorological data. The World Meteorological Organization (WMO), for example, has been using the Inmarsat-C data messaging service to send observation data from ships at sea via Inmarsat Land Earth Stations in Southbury and Goonhilly in the United Kingdom of Great Britain and Northern Ireland. This global network of observatories using Inmarsat systems contributes to the prediction and monitoring of cyclones, hurricanes and typhoons and other variables affecting maritime weather.

45. Under the auspices of its Regional Centre for Training and Applications in Agrometeorology and Operational Hydrology (AGRHYMET) programme, WMO has recently established a network of land-based monitoring stations in western Africa. A regional centre is located in Niger. Observation posts in nine countries, each of them equipped with an Inmarsat-A portable satellite communication system, report regularly on climate and soil conditions in real-time, complementing GIS and remote sensing data. Such information enables better medium- and long-range planning of agriculture and forestry activities, and helps more effective mitigation in an area covering millions of square kilometres. UNEP is another Inmarsat user in Africa.

46. Inmarsat terminals coupled with appropriate sensors provide supervisory control and data acquisition. Such equipment can play a vital role in providing or improving the monitoring and early warning functions, even from the most remote areas. The monitoring of geothermal and volcanic variables, tectonic-plate movement and pressure ridges helps to identify potential volcanic or earthquake activity.

47. The United Nations has also recognized the utility of Inmarsat portable satellite communications systems. Its United Nations Disaster Assessment and Coordination (UNDAC) teams, dispatched to a disaster site within hours, routinely carry messaging or phone/fax satcoms when assessing disasters. Their timely reports help to mobilize experts, supplies and equipment during the crucial 24-72 hours after disaster strikes.

48. The media also uses Inmarsat systems to report on disasters, especially for the transmission of compressed and slow-scan videos, still pictures and direct, high-quality audio broadcasts. The media play a big part in highlighting a country's plight, which can help to expedite external assistance. However, it is not only the media who need accurate and timely information. During the acute phase of an emergency, speedy and accurate transmission of all relevant information is a major requirement for effective work by disaster relief organizations. Lists and reports can be compiled quickly and transmitted via mobile satellite communications systems to disaster relief coordinators and other agencies using existing software programs for the management of personnel and supplies.

49. Immediately following a disaster, field workers in their vehicles or trucks carrying relief supplies often become immobilized due to local conditions. Therefore, regular communications and position reporting is highly desirable. Using Inmarsat mobile satellite communications systems and GPS, operations control is able to monitor the progress and location of all equipped vehicles, as well as send messages to them, regardless of the state of the local infrastructure, weather conditions and other impediments.

50. The introduction by INTELSAT of the new demand assignment multiple access (DAMA) service, especially for thin-route communications, will enhance connectivity in devastated areas. It will make digital satellite public switched services available to more users, especially in rural and remote areas. DAMA is a flexible, pay-as-you-use service, offering improved connectivity at a low cost, while providing a complete digital solution for thin-route operators.

51. INTELSAT plans to introduce thin-route DAMA in April 1996 on a global transponder on the INTELSAT 605 at 24.5° east covering its Atlantic Ocean region. This means that all gateway stations equipped with DAMA will be able to communicate with each other. Implementation of DAMA service in the Indian Ocean and Pacific Ocean regions is expected shortly thereafter. DAMA will benefit all users of the system, particularly those in developing countries. INTELSAT expects DAMA to be of great benefit in re-establishing communications after natural disasters. By bringing in fly-away transportable antennas, it will be possible to instantaneously re-establish contact with the rest of the world on the DAMA network.

52. In 1959, when Volunteers in Technical Assistance (VITA) was created to provide technical information and assistance to individuals and groups in developing countries, the first inquiries came from Africa. Africa is still the principal user of the VITA Inquire Service. VITA also supplies information on natural disasters and human-made crises such as civil strife and refugee movements. In 1987, VITA established its Disaster Information Center.

53. One of the services provided by the Center is a telephone hotline. When called on by the Government of the United States of America for assistance in responding to a disaster, within one day VITA activates its telephone bank, selects and trains volunteers, and begins to record offers and donations of medicine and other commodities. The VITA hotline has provided information on civil strife, floods, cyclones, food shortages, earthquakes, droughts and rains in Algeria, Angola, Benin, Burundi, Cameroon, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Liberia, Madagascar, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Senegal, Somalia, Southern Africa, Sudan, United Republic of Tanzania, Uganda and Zaire.

54. VITA has identified that one of the major needs for development is reliable communications and that the principal global telecommunications operators have little interest in providing service in most developing countries. Therefore, VITA has developed its own communications programmes, which includes LEO satellites (VITASAT), terrestrial digital radio networks (VITAPAC) and electronic mail services (VITANET).

55. The VITA electronic bulletin board, VITANET, is a multi-line, commercial grade system that allows for on-line database searching, access to training materials, computer conferences, on-line surveys and file transfer utilities, all of which are enormously useful during a disaster and for disaster preparedness activities. VITANET software interfaces will make it possible to link the VITA satellite system and packet radio networks, so that fully-automated end-to-end communications are possible. In September 1994, VITA installed its own direct Internet host. To date, the disaster ListServ has 129 subscribers who have received approximately 20,000 documents. In addition, more than 12,000 documents were picked up through the its gopher. The VITASAT global electronic messaging network is a satellite-based communications system for commercial, government and non-profit users worldwide. It utilizes LEO store-and-forward satellites in polar orbit. This system will provide large message and file transfers over 9.6 kilobits per second (kbps) links and offers two basic services: e-mail/fax transmission, and supervisory control and data acquisition.

56. Local people need to be made aware of the situation and local relief agencies, such as fire or ambulance services, need to be alerted. If help is organized by international relief agencies, this should also be known to the local population. There are various methods for broadcasting information to the area affected by a disaster. It is possible, for example, to receive information directly from a satellite or for messages to be passed via cellular networks. However, the equipment to receive such information is normally only available to relatively prosperous sections of the community and as a result the coverage would be somewhat uneven.

57. The most commonly available receiving equipment is the transistor radio. It has been estimated that there are over two billion radios in use, with nearly half of those being in the developing countries. A system that could address a large proportion of these radios seems to have the best chance of achieving a high penetration. Broadcasting directly to these receivers must be done by terrestrial means. This can most conveniently and economically be achieved by use of the FM/VHF bands of frequencies, for which most transistor radios are already equipped. Distribution of the signal to the area concerned is most conveniently carried out by satellite. Existing satellite capacity is available and can be leased for this purpose.

58. The receiving equipment for the satellite signal can be a relatively simple receive-only Earth station with a 2.4 m antenna and a 64 kbps link. WMO already uses such a system and it can easily be extended for disaster applications. The information received by the station can be disseminated directly to the local population through transistor radios or directed to the local emergency services, as appropriate. Each receiver/transmitter combination has a coverage area of 40 kms in diameter in flat terrain.

D. Use of data from remote sensing satellites

59. Remote sensing has become an important source of geographic information on current land cover and land use needed for rational development and sustainable management of agricultural and forestry resources and for environmental protection. It is therefore increasingly used by FAO in its programmes and field projects being conducted on the basis of the recommendations contained in Agenda 21.[1] However, until now, remote sensing has been largely technology-driven. Users have to compromise to fit their information requirements to the parameters of available remote sensing data. Furthermore, the countries that have the most pressing need for remote sensing do not have the resources to build the necessary capacities for its efficient use.

60. The increasing volumes of image data that are generated or the number of image products that are sold should not be used as a measure to gauge the success of satellite remote sensing. The ultimate criterion of its success will be the extent to which remote sensing will have contributed to the quality of life on Earth. Greater international effort should made to apply new remote sensing and GIS capacities where they are needed most: for monitoring environmental degradation and for implementing programmes for the sustainable management of natural resources in order to safeguard them for future generations. Particular attention should be given to the needs of developing countries and to strengthening their national remote sensing and GIS capacities.

61. The Regional Remote Sensing Project (RRSP) of FAO is a component of the Early Warning System for the Southern Africa Development Community (SADC) region. Output from this project is fed into the combined physical and socio-economic data used by the Regional Early Warning Unit (REWU) and the Household Food Security Project. The main objective of the present phase of the project is to strengthen national and regional capabilities in the area of remote sensing for early warning and food security by the establishment of an operational information system. As such, RRSP is developing national capacities for the analysis and interpretation of coarse-resolution satellite imagery and for the subsequent generation of information products.

62. At present, satellite data processed by the project and the resulting information products are sent to the contact points and a number of users in the SADC region using mail courier services. The current phase of

the project will see specific attention being given to the transfer of the processing technology to the principal contact points in the countries. To support this, e-mail links are being established between RRSP, REWU and meteorological services in the SADC countries. Finally, the project will establish a low-cost integrated satellite data acquisition system for NOAA and METEOSAT data in Harare.

63. Geologists, engineers, industrialists and planners are now more frequently using remote sensing in the evaluation of hazard situations. In hazard prevention studies, the interpretation of satellite data together with the analysis of geological records make it possible to reconstruct a historical overview of the occurrence of damaging events. This information can be used statistically to make a prognosis of potential risk in the occurrence of a catastrophe or for the production of thematic maps that show the spatial context in which hazards occur.

64. Remote sensing is not only used in preventive studies, but also in the monitoring of dynamic geological processes such as terrain deformation, neotectonic activities and flooding. Recently, a new technique using synthetic aperture radar (SAR) satellite data, called radar interferometry, has been introduced in the analysis of vertical displacement associated with fault movements.

65. On 17 July 1991, ESA launched the first European Remote Sensing satellite (ERS-1), a polar orbiting satellite that constituted a major development in remote sensing applications by providing new tools for assisting in natural disasters monitoring and relief. ERS-2 was launched on 21 April 1995 in order to ensure continuity of data acquisition. However, since ERS-1 is still fully operational, the two satellites are operated by ESA in a tandem mode that provides a unique opportunity for several applications.

66. The two ERS satellites provide a wealth of radar information for many applications. They are both equipped with several microwave sensors as well as an optical radiometer. The main radar equipment is the Active Microwave Instrument (AMI), which can be operated in an imaging mode as a side-looking SAR, thereby providing high-resolution image data in C-band (5.3 GHz) at regional scales. Because microwave radiation suffers very little attenuation in passing through clouds and rainfall (except very heavy thunderstorms), the ERS-1 and ERS-2 SARs provide images of the tropical areas that heretofore could not be thoroughly mapped with LANDSAT and SPOT because of the constant presence of clouds in the region. Furthermore, the complementarity between optical and radar images of the same area has already proven to be an excellent and powerful tool for advanced applications and an asset in natural disaster monitoring and relief.

67. On a global scale, the ERS-1 AMI SAR is operated as a wave scatterometer over water to generate SAR "imagettes" of 6 km x 5 km along the SAR swath at 200 km intervals. Through the analysis of the imagette spectrum, operational worldwide information on the wave systems, namely wave height and wave direction, is derived. Such products are disseminated within three hours from data sensing to nominated centres through the global meteorological network for subsequent assimilation into numerical analysis and forecast models.

68. The ERS-1 AMI can also be operated as a wind scatterometer to provide wind vectors at the ocean surface on a 25 km grid. Sea surface backscattering signals of radar pulses emitted at three different side-looking angles are measured on board and then elaborated on the ground through a C-band model to generate surface vectors with the same accuracy for conventional ground measurements. Like the ERS SAR wave data, AMI wind vectors are also disseminated operationally through the global telecommunication system. Data from the ERS wind scatterometer are of particular help in the tropical region, in the southern hemisphere and in the northern Pacific Ocean because of the very limited amount of available statistical data on these areas.

69. ERS-1 radar altimeter data provide worldwide surface information. Several measurements are derived at a global scale from backscattered signals of downward emitted radar pulses, including the height of sea and ice surfaces, the height of sea waves and the wind speed at the sea surface. Additional geodetic and

climatological information is generated from the former, which leads to the availability of some important climatic change indicators, such as anomalies in ocean topography (e.g. el Niño and la Niña) or in ice melting (e.g. Antarctic caps). The precise range and range rate equipment (PRARE), operational on ERS-2, allows precise orbit calculations to be made and accurate corrections to radar altimeter measurements to be implemented.

70. In addition, ERS satellites carry an along-track scanning radiometer (ATSR), a dual instrument constituted by an optical and a passive microwave radiometer. The optical radiometer on ERS-1 works in four infrared spectral bands, at 1.6, 3.7, 11 and 12 micrometers; three visible channels have been added to the ERS-2 version. Very accurate sea surface temperature measurements are provided globally on a 50 km grid, with an intrinsic original 1 km spatial and 0.1 K radiometric resolution. A dual viewing, oblique at 50 degrees ahead and vertical, together with internal black-body calibration leads to very accurate atmospheric corrections. The visible channels added to the ERS-2 radiometer allow the derivation of vegetation indices. The ATSR Microwave Sounder is a dual frequency passive radiometer, whose data are used primarily to correct radar altimeter measurements and to determine the atmospheric vapour content.

71. High-resolution satellite imagery (HRSI) is an important tool for increasing the efficiency during the planning and implementation phases of refugee work relief operations. Until recently, the highest resolution satellite images commercially available have been 10 m resolution SPOT images. Currently, images with 2 m resolution obtained from Russian military satellites are commercially available. This information can be used to obtain estimates of refugee-camp population, area and growth rates. The interpretation of such high-resolution images should be strongly linked to the United Nations in order to utilize already established communication lines with relief agencies.

72. In the near future, sensors with ground resolution down to 1 m will be commercially available. The data distribution systems of these satellites will be vastly improved in comparison to the present ones. However, an unfortunate trend might be seen in the data distribution plans of some commercial companies that intend to offer exclusive rights to the customers on a first-come, first-served basis, denying access to the images for late customers. It is therefore important for the United Nations to play an active role in forming policies to distribute HRSI.

73. Data from satellite-based radar systems can also be used in many ways for natural hazard reduction. The most conventional use of radar data is the recognition of flooded areas by the dark signature of still water in a radar image associated with the all-weather capability of the instrument. The 1 m accuracy of the models created by ERS-1 data is unmatched by other space-based techniques. The dense spatial samplings (100 pixels/sq km) provided by radar interferometry in the detection of displacements associated with its accuracy (in the range of 3-10 mm) make it an important tool for assessing most natural hazards. This tool could be used as a cheap warning signal in the case of volcanoes, as was demonstrated in the case of the recent activity at Mount Etna. The ERS-1 satellite can also provide the data required for global monitoring of all potentially hazardous volcanoes. Radar interferometry can also contribute to the understanding of earthquakes, especially in poorly equipped areas because it does not require ground instrumentation.

74. Some current limitations of these techniques are linked to the physics of the atmosphere, the contribution of which can only be separated by the analysis of multiple image pairs and the change of the surface state in long periods of time that spoils the interference patterns. A high throughput system such as ERS-1 proved capable of delivering the many images required. Other limitations come from the features of current space-borne radar instruments, which were not designed for this purpose. The experience gained could be of help when designing better systems in the future. However, the built-in design margins of ERS-1 permit its operational use in the field of interferometry, for which it was not initially designed.

E. A global monitoring and warning satellite system

75. The Japanese Space Agency, NASDA, is emphasizing the development of data analysis technology for a variety of applications including natural disaster reduction. For the development of technology for data application in the field of natural disaster reduction, NASDA is considering cooperative research projects, such as the Global Earth Observation System (GEOS), the Advanced Earth Observing Satellite (ADEOS), the Advanced Land Observing Satellite (ALOS), and the Tropical Rainfall Measuring Mission (TRMM), with the international user community for the verification of algorithms to be applied to actual case-studies. NASDA is also planning to reflect user requirements in the field of natural disaster reduction to future programmes.

76. The purpose of the World Environment and Disaster Observation System (WEDOS) and the Global Disaster Observation System (GDOS) of the Society of Japanese Aerospace Companies, Inc. is to provide continuous operational monitoring of the Earth's environment in order to detect and mitigate natural disasters and human-induced accidents. A total of 26 remote sensing satellites will be launched into low altitude, sun synchronous and circular orbits together with 12 (6 in-orbit spares) data relay satellites in geostationary orbit. The monitoring of short-term changes is indispensable to the prevention of disasters and that type of monitoring could be accomplished by using existing technologies. Both systems therefore concentrate on observing environmental changes that occur over short periods (e.g. oil pollution and red tides) and the simultaneous observation of phenomena occurring globally over the surface of Earth (e.g. wind speed and direction of sea surface).

77. Consequently, any location in the world could be observed by WEDOS at least once a day with 20 m resolution; therefore irregularities and environmental changes can be detected immediately. More precise observations of the damaged areas, with 2 m resolution, will also be possible several times a day. GDOS is a modified version of WEDOS, which facilitates the location of disasters and is capable of repeatedly observing a disaster site.

78. The payloads of the satellite segment of both systems would be designed to monitor the land and ocean environment, the geosphere, hydrosphere and meteorological conditions, with the aid of visible, near infrared, microwave, short-wave and thermal radiometers, synthetic aperture radar, radar altimeter and scattering lidar. The ground segment would comprise a mission management centre, satellite control centres, a master ground station and local user stations. Observation data would be received by the master ground station via data relay satellites and would then be recorded and processed. The processed data would be distributed to each local user station in the world. To implement any of these two systems it is mandatory to develop an international consensus on the importance of the subject of disasters and to gain support from the general public, scientific community, governmental and United Nations entities that are in charge of the natural environment and disaster prevention.

Notes

[1] *Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992* (United Nations publication, Sales No. E.93.I.8 and corrigenda), vol. I: *Resolutions Adopted by the Conference*, resolution 1, annex II.

Annex I

PROGRAMME OF THE WORKSHOP

Time	*Subject*	*Speaker*
	Chairman: Prof. C. J. Chetsanga (Zimbabwe)	
Monday, 22 May		
0900-0945	Opening ceremony	UN, ESA, Zimbabwe
1000-1030	Keynote address Effects of disasters on modern societies	J. C. Scott, IDNDR
1030-1100	Keynote address Role of space technology in disaster assistance	M. Fea, ESA
1100-1115	**Break**	
1115-1200	Southern Africa: Challenges for Long-Term Disaster Reduction: elements of telemedicine	A. Holloway, International Federation of Red Cross and Red Crescent Societies
1200-1330	**Lunch**	
	Chairman: Dr. M. Fea (ESA)	
1330-1415	FAO activities related to environmental disasters	G. Farmer, FAO
1415-1500	Space techniques to confront geological hazards	R. Missotten, UNESCO
1500-1515	**Break**	
1515-1600	GIS and remote sensing in Zimbabwe	D. T. Semwayo, ERSI
1600-1645	Space techniques to combat drought and desertification: an overview	H. Beukema, UNEP
	Chairman: Dr. L. Chikuni	
Tuesday, 23 May		
0900-0945 0945-1030	Use of ERS-1 data for disaster mitigation Application of radar interferometry Using ERS-1 satellite data	M. Fea, ESA D. Massonnet, CNES France
1030-1045	**Break**	
1045-1130	Remote sensing component of the early warning system for SADCC countries	G. Farmer, Dept. of Meteo Services Zimbabwe
1130-1215	The use of remote sensing technology in combating forest fires.	W. Rugumanu, University of Dar-es-Saalam Tanzania

Time	*Subject*	*Speaker*
1215-1345	**Lunch**	
	Chairman: Dr. W. Botha (South Africa)	
1345-1430	Remote sensing satellites for disaster reduction	L. Walter, NASA USA
1430-1515	Globalstar for disaster communications in Africa	W. Thatcher GLOBALSTAR
1515-1530	**Break**	
1530-1615	The use of Inmarsat in disaster-relief operations	E. Staffa, Inmarsat
1615-1700	Inmarsat-B and -M terminal demonstrations	Inmarsat/AVITRONICS
	Chairman: Miss L. Muvoti (Zimbabwe)	
Wednesday, 24 May		
0900-0945	An overview of remote sensing in South Africa with emphasis on agricultural applications	N. C Badenhorst T. S. Newby Agricultural Research Council, South Africa
0945-1030	Earth observation satellite programmes in Japan for natural disaster reduction	T. Igarashi, NASDA Japan
1030-1045	**Break**	
1045-1130	WEDOS: A world environment and disaster observation system GDOS: A global disaster observation satellite system	T. Kuroda, SJAC/NEC Corp., Japan
1130-1215	Using high-resolution satellite images to monitor "refugee movement"	E. Bjorgo, Nansen Env. & R. Sen. Centre Norway
1215-1345	**Lunch**	
	Chairman: Mrs. A. Howman (South Africa)	
1345-1430	Desertification control in Ghana	G. T. Agyepong University of Ghana Ghana
1430-1515	Space techniques to combat hydrological hazards	L. Walter, NASA USA
1515-1530	**Break**	

Time	*Subject*	*Speaker*
1530-1615	VITA Disaster Information Centre	J. Sedlak, VITA (USA)
1615-1700	Discussions	
1830-2000	**Reception**	Government of Zimbabwe
	Chairman: Prof. S. Ogedengbe (Nigeria)	
Thursday, 25 May		
0900-0945	Assessment and initial communications strategy for post-disaster coordination using satellites	C. Hughes, ESA/ESTEC
0945-1030	Resilience of satellite communications systems in a disaster situation	John Akumu, INTELSAT
1030-1045	**Break**	
1045-1130	Practical uses of satellite terminals for disaster relief operations and the establishment of such facilities at the national level	J. C. Scott, UN/DHA
1130-1215	Necessary capabilities for addressing disaster mitigation and reduction	A. A. Abiodun, UN/OOSA
1215-1345	**Lunch**	
1345-1700	Working group (discussions)	
1830-2000	**Japan evening**	
Friday, 26 May		
0900-1200	Technical visitations Environment and remote sensing institute - ERSI and SADC/FAO Early Warning Unit	Zimbabwe
1400-1700	Discussion and adoption of the recommendations	
1700-1730	**Closure**	United Nations/ESA Zimbabwe

Annex II

WORKING PAPER ON DATA SUPPLY (GROUP A)

Objectives

(a) Acquisition of the right data (type, format, supporting medium) and their delivery in a timely fashion.

(b) Establishment of multidisciplinary database(s), including purchasing, operating, maintaining and upgrading of the appropriate facilities needed for the scope.

Issues

Funding (cost)

Adequate and sustainable funding for facilities and training.

(a) Earth observation data

With respect to meteorological satellites, data gathering is routinely performed as a normal operation, but one issue is the planned encryption of METEOSAT data by EUMETSAT, with the consequent cost of the encryption software key.

With respect to high resolution satellite data, the cost is considered too high for the systematic acquisition to support prevention; data must be paid for even for coverage related to a natural disaster.

Funding for data archiving should also be identified.

(b) Communications

Operational and maintenance costs associated with data acquisition.

Operational and maintenance costs required to ensure the timely delivery of data to users.

SAT regulations.

Technology

Earth observation

Availability of suitable hardware and software packages (including licences) for acquisition, archiving, pre- and basic processing, distribution display and stable power supply. These must include upgrading as required.

Communications

Choice of the system(s) to be used.

Quick delivery of data can become a problem in case of emergency.

Expertise

Earth observation and communications

Adequate specialized training.

Technical expertise in data handling and in maintenance.

Retention of qualified and experienced manpower.

Public communication

Earth observation and communications

Political commitment for supporting and funding data supply activities is needed because such activities are usually proportional to the interest in the information that is generated from the data themselves.

Mechanisms needed for achieving objectives and tackling issues

A prerequisite is a thorough analysis of needs and goals against the actual situation at the national level. Regional and/or international cooperation should be sought, in particular in domains such as cost sharing, training, thematic workshops and seminars, and technical awareness.

A. Funding

(a) Earth observation and communications
National commitments to be reflected in the relevant budget lines
Other funding sources to be explored
Private institutions in the national context should be approached.

B. Technology

(a) Earth observation
Countries must express data supply requirements in order to ensure data availability.

(b) Communications
Countries should address the amendments to data regulations in order to allow data availability as needed.

C. Expertise

(a) Earth observation and communications
Ensure thematic on-the-job training
Ensure adequate training for trainers.

Recommendations

General

In view of the importance and utility of Earth observation data in general, political commitment is needed to ensure adequate and sustainable support to data supply activities; priority should be given to

ensure the timely distribution of data with special dispensation from the ministry of postal, telephone and telegraph (PTT) during critical periods

Specific

Full ground station coverage of the African continent should be ensured for high resolution satellite data.

Data should be made available free of charge to relevant disaster management institutions on the occurrence of sudden short-term natural disasters, such as floods, earthquakes, volcanic eruptions, land/mud-slides, weather storms and oil spills.

Meteorological satellite data encryption should be waived for use by relevant public institutions.

Annex III

WORKING PAPER ON INFORMATION GENERATION (GROUP B)

The assumption is made that data are available and supplied. We undertake:

Processing
Analysis
Interpreting
Identify user needs
Dissemination of raw and value-added data
Data integration
Development of techniques and methodologies

Issues

Funding

Identify role of players

Identify areas requiring funding, including:

Equipment
Software
Personnel
Facilities
Data supply
Products
Communications links
Research and development
Maintenance
Information dissemination
Field verification
Training
Consultants

Cooperative studies
Sponsorship - applications
Ensure government budgeting
Project proposals
Undertake marketing campaigns
Introduce cost recovery methods.

Technology

Identify and acquire appropriate equipment
Develop data transfer protocols
Ensure compatibility of systems
Ensure reliable, timely, resilient, affordable, efficient telecommunications links
Advise on database structures
Maintenance and support to ensure sustainability
Optimum utilization of hardware and software
Development and identification of appropriate/desired techniques and methodologies
Ensure application of techniques.

Expertise

Identify tasks
Find appropriate personnel
Provide bursaries for technical education and continued training

Develop in-house technical training programs and identify external training facilities
Improve conditions of service
Ensure career paths
Maintain critical mass: avoid one-person shows, ensure back-up support
Keep abreast of technological developments
Establish regional training centres
Produce user manuals.

Public communications

Aim to produce user-friendly products for professional and general public
Promote proactive awareness programs (and credibility of disaster managers)
    Professional
    Public
    Key decision makers
Ensure targeted communications of information
Produce pamphlets etc.
Take into account culture and language
Identify communications protocols
Identify and utilize all communications links, including: PTTs, TV, radio, newspapers, leaflets, electronic mail and Internet
Disseminate user-friendly information
Develop a national education curriculum.

Recommendations for a practical programme

Establish steering committee
Perform needs analysis
Carry out inventory of existing status: what's happening, funding, personnel, systems and data availability, and data dissemination
Identify what procedures are required
Develop plan of action, proposal, budget
Obtain implementation and budget approval
Establish facilities
Develop capability and become operational
Ensure sustained operations
Carry out progress evaluation.

Annex IV

WORKING PAPER ON DECISION PROCESS (GROUP C)

Objective

To highlight the guiding principles with regard to the decision-making processes required for the optimal application of remote sensing and communications technology in disaster management.

Issues

To establish a high level coordinating body for disaster management.

To establish an interdisciplinary focal point for each department both internationally, nationally, regionally, subregionally and locally.

To prepare an effective national disaster management plan to identify disaster types (i.e. drought, floods, cyclones, locusts and refugees) and assign appropriate responsibilities to organizations such as government departments, ministries, non-governmental organizations, communities and individuals. The ultimate responsibility lies within the government. A disaster management plan should comprise preparedness, mitigation, relief and recovery, and the funding thereof.

A disaster management plan should address: capacity building, civic education, training, communications elements and the role of women.

Recommendations

Countries should modify national legislation to allow proper functions of disaster mitigation, including areas such as telecommunications policy, movement of technology, free flow of information within the country and across its borders, as appropriate.

Governments should promote bilateral and multilateral agreements concerning, for example, data equipment and telecommunications.

National governments should be encouraged to take disaster mitigation problems seriously and include the needs of disaster management in their national budget.

Specific decisions should be taken at appropriate levels commensurate with the task and expertise required.

Experience with disaster management gained by certain countries should be utilized, for example Malawi, South Africa and Zimbabwe, because each has an established disaster management plan.

Space-based technologies, such as remote sensing and satellite communications, should be used to the extent possible to focus risk assessment, identification of vulnerable areas, suggest preventive measures and monitor events.

Countries should maintain and strengthen cooperation with established agencies, for example, ESA, NASA and NASDA, and coordinating bodies, such as the United Nations, Office for Outer Space Affairs, and the telecommunications companies where applicable.

Regarding funding, it is understood that regional, national and local governments must rationalize a strategy for funding disaster management planning. Such a strategy must include a significant commitment on the part of these governments to support essential initiatives. It is also understood that the costs of infrastructure building, both in technological and human terms, is expensive, and donor governments and international funding agencies will be looked to for support in terms of technical assistance, education and training and, when necessary, financing. In this respect the workshop endorses the report of the International Decade for Natural Disaster Reduction's *Yokohama Strategy and Plan of Action for A Safer World, Guidelines for Natural Disaster Prevention, Preparedness, and Mitigation,* especially item 13, and all its sections.

Annex V

WORKING PAPER ON IMPLEMENTATION/EXECUTION (GROUP D)

Key activities are directed towards:

GOAL: to achieve sustainable development and socio-economic recovery following a disaster.

Prevention	Relief
Preparedness	Rehabilitation/reconstruction

Objectives

Communicate the plans across effective parties; monitoring the plans; execution of the plans; and evaluation of the plans and feedback.

Issues

Identification of the stakeholders in the disaster.

Identification of appropriate means of communication.

stakeholders acceptable packaging of information on plans.

Resources inventory and assessment.

Training programmes for stakeholders (e.g. on fire, floods).

Performance criteria.

Formulating remedial process.

Capability to evaluate the plans

Mechanisms

Establishment of an implementing authority and clear chain of command, to ensure ownership and responsibility for the execution of a disaster management plan.

Development and installation of appropriate communication network.

Establishment and implementation of participatory communication mechanism.

Setting up administrative mechanism for establishment and maintenance of physical and financial resource databases and decision - information databases.

Development and implementation of suitable training programmes (including technical training, managerial training and project planning training).

Development and implementation of participatory process for setting performance criteria.

Establishment and operationalization of the monitoring team.

Development and implementation of participatory evaluation mechanism including feedback.

Recommendations

Encouragement of formation of indigenous non-governmental organizations focusing on disaster management.

Establish national institutions for disaster management (e.g. Prime Minister's office).

Development of a programme to ensure routine accessibility to disaster decision - support information (e.g. remote sensing data, weather data and demographic data).

Development of guidelines for the installation of communication networks to ensure compatibility within the SADC subregion.

To task a United Nations agency to research and develop manuals and guidelines for disaster management (e.g. participatory communication mechanism for disaster management; administrative mechanism; resource databases and decision information database).

FAO/SADC Food project should be reformulated to include disaster management in general.

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

MICROSATELLITES AND SMALL SATELLITES: CURRENT PROJECTS AND FUTURE PERSPECTIVES FOR INTERNATIONAL COOPERATION

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), at its eighth session (A/AC.105/571, annex II, para. 17), proposed that several studies on space applications should be undertaken by the Office for Outer Space Affairs in view of the recommendations adopted at the workshops, seminars, symposia and conferences organized by the United Nations Programme on Space Applications. The Working Group of the Whole identified a number of possible subjects for such studies, including microsatellites and small satellites, current projects and future perspectives for international cooperation.

2. The report of the Working Group of the Whole was adopted by the Scientific and Technical Subcommittee at its thirty-first session (A/AC.105/571, para. 22), and the recommendations contained therein were endorsed by the Committee on the Peaceful Uses of Outer Space in its report on the work of its thirty-seventh session[1] and by the General Assembly in its resolution 49/34 of 9 December 1994.

3. The present study has been prepared by the Secretariat in response to the request of the Working Group of the Whole. The study, which is available in English only, is presented in the annex to the present note. The purpose of the study was to give an overview of the rapidly evolving field of small satellites, which should be easily accessible even to countries with limited or newly conceived space programmes. The study was prepared using a variety of national and international sources that are listed in the selected bibliography at the end of the study. It was also sent in draft form to external experts for comments. A summary of the study is provided below.

SUMMARY OF THE STUDY

4. Small satellites have already been used with considerable success by many organizations. Their attraction lies in the promise of low-cost and short development time, which is made possible by the use of proven standard equipment and techniques, together with a realistic expectation of performance. The space age began with the launching of small scientific satellites in 1958, the International Geophysical Year. Those satellites were small because of the limited capacity of the first space launchers. After a modest beginning with small, simple and lightweight satellites, space systems evolved into large, complex and expensive space platforms for scientific research and other applications that often require many years of development prior to launch.

5. While such large platforms exist and will continue to exist, there has recently been a growing interest in returning to the use of small satellites, which can be launched within a few years after programme initiation. As a consequence of the evolution of space-related technologies, this class of spacecraft can make significant space capabilities accessible to a wide number of users, ranging from students in secondary schools and universities to engineers and scientists in every country in the world. In many ways, projects involving small satellites are ideal for extensive international cooperation.

6. The development of small satellites will not replace that of large satellites, as the goals and issues involved are often different. Missions involving small satellites can, however, be a complement to large satellite missions. By exploring new methods and techniques, small satellites can be a tool for pioneering experiments and technologies for future missions involving larger satellites.

7. Small satellites have several advantages over large satellites and these hold true no matter who the users are: more frequent, and a larger variety of, mission opportunities; more rapid expansion of the technical knowledge base; greater involvement of local industry; and greater diversification of potential users. Moreover, even a country with a modest research budget and little or no experience with space technology can afford to participate in missions involving small satellites. Small satellites also offer excellent opportunities for training students, engineers and scientists in different disciplines, including engineering, software development for computers on board and on the ground and management of sophisticated technical programmes.

8. Recent technological progress in many areas means that small satellites can offer services previously only available from much larger satellites. Fairly sophisticated scientific and technological experiments, as well as application missions, can be flown in space at modest costs. The areas of application include: space physics, astronomy, astrophysics, technology demonstrations, communications experiments and acquisition of Earth resource data, including disaster information.

9. The definition of a small satellite varies, but an upper limit of about 400 kg (in exceptional cases 500 kg) is usually adopted, within which there are two main categories: small satellites (or minisatellites), which weigh about 100-400 kg; and microsatellites, which weigh less than 100 kg. A typical "small satellite mission", including launch, generally costs less than US$ 20 million and most microsatellite projects cost approximately US$ 3 million.

10. A central issue in any small satellite mission is the optimum balance between programme complexity and risk. Small satellites are likely to offer new opportunities for procurement methods. The selected model philosophies are important in terms of both risk and cost and, as a maximum, a protoflight approach is acceptable for such programmes. The advantages of small satellites are as follows:

(a) Orbital parameters optimized to individual instrument requirements;

(b) Augmentation of conventional satellite programmes, such as additional capability, redundancy for critical missions, or replacement of a failed instrument;

(c) Missions with limited lifetime and/or coverage requirements;

(d) Improved responsiveness to the end-user (more frequent launch opportunities and increased mission flexibility for individual instruments, plus schedule independence);

(e) Quick-reaction, launch-on-demand launches using low-cost dedicated vehicles (e.g. crisis monitoring, replacement after an in-orbit failure, or monitoring of unexpected environmental conditions);

(f) Relaxed reliability owing to the shorter lifetime or agreed, lower levels of product assurance or lower-quality parts as appropriate to lower development costs;

(g) Reduced satellite design complexity (e.g. simplified interfaces, optimized for instrument requirements), shorter development schedule and suitable test-bed for proving technique and/or technology.

11. There are three general classes of orbit that may be suitable for small satellites: the geostationary orbit (GSO), the highly elliptical orbit (HEO) and the low Earth orbit (LEO).

12. GSO is where the satellite appears fixed relative to the ground, thus allowing continuous visibility and simplifying the ground segment and operational requirements. Because of the large space-to-ground distance involved, however, the data rates are small, or larger ground antennas and higher electrical power on board the spacecraft are required. This orbit is usually reached from a standard geostationary transfer orbit (GTO) provided by a large launch vehicle.

13. The use of GTO is interesting as it could benefit from frequent piggyback launch opportunities while avoiding the complexity and extra costs associated with an apogee propulsion system.

14. LEO is generally preferred for small satellite missions. Small launch vehicles may be used, offering flexibility in the selection of the orbit parameters; piggyback launches may also be used. A low-energy transmitter on board is sufficient because of the short distance from the ground, but infrequent and short visibility periods are a drawback, leading to some ground-segment and operational complexity. A distinction should be made between the near equatorial or low inclination orbits, for which the visibility zone will be limited to the topical zone, and the polar and quasi-polar (Sun-synchronous) orbits that allow accessibility to any point on Earth, either for communication (e.g. store and forward) or for remote sensing of Earth.

15. The current and future development of small satellites is closely linked to the appearance of new, low-cost launchers (Pegasus, Taurus etc.) and lower-cost launch opportunities on existing vehicles (for example, Ariane-4 or small canisters on the Space Shuttle). The potential availability of cheap launchers has spurred much of the recent surge of interest in small satellites, which was initially driven largely by defence and global civil communication programmes of the United States of America. Of the major low-cost launchers of European countries and the United States, only Pegasus and Taurus are flight-proven. Conestoga is planned for flight in the near future, development of the Italian San Marco Scout has not yet started (although its forerunner, the United States Scout, has been operated for many years) and the Ariane-5 derivative programme should be completed in 1999.

16. In order to maximize their potential, small launcher developers must apply the same innovative, low-cost design approach used on small satellites. Launch costs represent a large portion of total programme costs (generally over 25 per cent) and satellite mass and size must therefore be constrained to take full advantage of low-cost launch opportunities. Options include:

(a) Small dedicated launchers;

(b) Multiple launch of several small satellites, nominally on Ariane-4 or Ariane-5 for European missions (e.g. Cluster scientific satellites of the European Space Agency (ESA));

(c) Flight opportunities on larger launchers (Arianespace has strongly promoted its vehicles for this purpose, with Ariane-4 offering: Ariane Structure for Auxiliary Payloads (ASAP) for piggyback microsatellites (up to six 50 kg satellites (300 kg total)); Ariane Radioamateur Satellite Enseignement Espace (ARSENE)-type configuration for satellites of up to 200 kg; and SPELDA Dedicated Satellite (SDS) for satellites in the range of 400-800 kg within the short Ariane Dual Launch External Bearing Structure (SPELDA) adapter.

17. Similar options are provided by other medium-sized or large launchers, for example, the United States Atlas Centaur and the Delta-2.

18. Requirements for the ground segment of a small satellite system vary enormously depending on the application area. At one extreme, low data rate sensors with only local or regional coverage on missions with low tracking and command requirements impose relatively low demands on the ground segment, possibly comprising only 10 per cent or less of total programme costs. More complex data retrieval and processing requirements could result in ground segment costs of up to 50 per cent of total programme costs. Assuming that ground segment costs tend to average 25 per cent of total programme costs, it is clearly important to identify potential savings in the ground segment in concert with those of the space segment.

19. In attempting to reduce the ground segment costs, there are limits on simplification because it is still necessary to ensure the achievement of capabilities such as reliable operation, rapid response to critical commands and regular form of data on time and with low loss. The ground segment model, which forms the basis of any technical and cost assessments, must include not just the provision of the ground stations, but also ground communications infrastructure, mission control etc. Very small, in some cases transportable, stations have been made commercially available by several suppliers in European countries and in the United States. Commercial providers of remote sensing data are likely to press for the adoption of such approaches in attempts to reduce the cost of distributing and processing the data.

20. Space science activities are obviously valuable, and most space-faring nations have begun their involvement in this field with small scientific satellites. A university environment is often an ideal environment for the development of space activities and, because such projects often require the creation of new laboratories, these facilities are a lasting, beneficial by-product of such projects. Thus the usual spin-offs of a space programme, the acquisition of technology and the development of industrial organization and management methods, will begin to accumulate at the national level as students leave the university and enter local industry.

21. The first small scientific satellite of Argentina will be the Scientific Applications Satellite (SAC-B), which is being developed jointly by its national space agency, the National Commission for Space Activities (CONAE), and the National Aeronautics and Space Administration (NASA) of the United States. The 190 kg satellite is to be launched in 1996 by a Pegasus rocket into a circular orbit of 550 km with an inclination of 37 degrees. SAC-B will be inertially stabilized and permanently oriented to the Sun. It will monitor energetic X-rays from solar flares and survey the sky with X-ray charge-coupled device (CCD) sensors along an axis perpendicular to the Sun line.

22. Between 1978 and 1991, scientific microsatellites weighing 15-50 kg were developed for the Magnetosphere-Ionosphere (MAGION) research programme in the former Czechoslovakia. MAGION-1 was launched on 24 October 1978 as a subsatellite of the INTERCOSMOS-18 geophysical satellite. Although it was designed for an operational lifetime of three weeks, MAGION-1 remained operational for three years.

MAGION-2 and MAGION-3 were launched into high-inclination low-eccentricity orbits (with an altitude of 500-3,200 km) as part of the ACTIVE and Ariane Passengers Experiment (APEX) mother-daughter active space missions launched on 28 September 1989 and on 18 December 1991, respectively. The MAGION-4 subsatellite was successfully launched by a Molniya launcher from the cosmodrome at Plesetsk, Russian Federation, on 3 August 1995, as part of the INTERBALL-tail mission. MAGION-5 is currently scheduled for a 1996 launch.

23. The Central European Satellite for Advanced Research (CESAR) is a spacecraft of about 300 kg that will fly in an orbit with a perigee of 400 km, an apogee of 1,000 km and an inclination of 70 degrees. The scientific mission is related to the study of the magnetosphere, ionosphere and thermosphere of Earth. Ten different experiments, provided by scientists from Austria, Czech Republic, Hungary, Poland and Slovakia, will be accommodated on the spacecraft, which is being funded by the Italian Space Agency (ASI) and designed by Alenia Spazio. This mission is one of the objectives of the cooperation among the countries of the Central European Initiative.

24. Space industry and research institutions in Finland have acquired experience in satellite payloads and instrumentation through their associate membership in ESA and have long been active in remote sensing and other space-related disciplines. To initiate a study of a Finnish small satellite (FS-1), Finnish institutes defined their interests by contacting selected institutes with an unofficial announcement of opportunity and by asking for proposals. After the proposal phase, system design was performed for two alternatives: a scientific satellite and an Earth observation satellite. Each satellite would contain a technology demonstration package in which new electronic components would be tested in the space environment.

25. The French National Centre for Space Studies (CNES) is currently considering the following small scientific satellites:

(a) Mission SAMBA: registration of the local fluctuations of 3 kelvin radiation from the big bang (similar to the Cosmic Background Explorer (COBE) satellite of the United States) and detailed measurement of possible anisotropies;

(b) Mission COROT: astroseismology, new data on the convection and internal rotation of stars by long-term measurement of stellar oscillations;

(c) Mission IBIZA: registration of the plasma accelerated in the geomagnetic auroral regions, interaction of ionized particles with the ionosphere and magnetosphere of Earth, creation of electromagnetic disturbances;

(d) QUICK-STEP: verification of the equivalence of the inertial and gravitational mass (theory of relativity) with a relative precision of 10^{-17}.

26. On 3 February 1994, the small satellite of the University of Bremen, BREMSAT, was carried into orbit by the United States Space Shuttle Discovery. The spacecraft, which weighed 63 kg, waited six days in its Get Away Special (GAS) container before it was deployed into its initial circular orbit of 350 km. The satellite carried six experiments with different scientific objectives, including heat conductivity under microgravity, micrometeorite and dust particle distribution, atmospheric atomic oxygen mapping and re-entry pressures and temperatures. The satellite functioned until its in-orbit decay on 12 February 1995.

27. In developing its indigenous launching capacity, India prepared a series of small technology development and scientific satellites called Rohini and the Stretched Rohini Scientific Satellite (SROSS) series. The Rohini satellites were launched between 1980 and 1983 and carried a landmark sensor payload including a solid state camera. More than 2,500 frames in both visible and infrared bands for identification of landmarks and altitude and orbit refinement were obtained. The orbital mass of the Rohini satellites was about 42 kg.

28. SROSS-C and SROSS-C2 were launched on 20 May 1992 and 4 May 1994, respectively. They each carry two scientific payloads. The first is the retarding potential analyser, consisting of two planar detectors to measure plasma parameters and to investigate the energetic structure of the equatorial ionosphere. The second is the gamma-ray burst experiment, consisting of two scintillation detectors to study celestial gamma-ray bursts in the energy range of 20-3,000 kilo-electronvolts.

29. The Instituto Nacional de Tecnica Aeroespacial (INTA) of Spain, situated at Torrejón de Ardoz, has been entrusted by the Government with the direction of a research project for the development of a Spanish space system, called MINISAT. The system will consist of a multi-purpose platform (service module), payload module and an associated ground segment. Both the platform and the subsystems comprising it are modular in character. The platform will be capable of receiving, integrating, operating and carrying on board a payload module by means of standard interfaces. This will permit all the required adaptations for a particular mission to be easily conducted. The platform will be able to carry payloads with masses that vary between 80 and 500 kg. The first of these satellites will be a MINISAT mission carrying a payload module (PLM-1).

30. The first Swedish-built satellite was the 283 kg Viking, which was launched into low polar orbit in 1986 in a piggyback configuration with the French remote sensing satellite, satellite pour l'observation de la Terre (SPOT). The scientific objective of the Viking satellite was to study ionospheric and magnetospheric phenomena at high geomagnetic latitudes in the altitude region of up to about two Earth radii. Simultaneous measurements were made of electric and magnetic fields, particle distributions, plasma composition and waves, as well as imaging in the ultraviolet of the aurora variations.

31. A more advanced small scientific satellite, called Freja, was launched on 6 October 1992 by a Chinese launcher. This satellite of 214 kg is designed for auroral research and other related magnetospheric phenomena.

32. Because Swedish magnetospheric scientists are very interested in the possibilities of small satellites, a compact satellite platform has been developed that is 10 per cent of the mass of the Freja. This new microsatellite, called Astrid, is shaped like a box with sides measuring approximately 50 x 50 cm and has a mass of 25 kg in its stowed configuration. It is spin-stabilized with a Sun-pointing capability and deployable solar panels. The first Astrid was launched on 24 January 1995 from the cosmodrome at Plesetsk on a Cosmos launcher.

33. The best example of the small satellite programmes in the United States is the NASA Small Explorer (SMEX) programme, which provides for frequent flight opportunities for highly focused and relatively inexpensive science missions. Each SMEX spacecraft weighs approximately 250 kg and each mission is expected to cost approximately US$ 50 million for design, development and 30 days of in-orbit operations. The first satellite of this series, the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX), was launched on 3 July 1992. It has been successfully investigating the composition of local interstellar matter and solar material and the transport of magnetospheric charged particles into the atmosphere of Earth. The Submillimeter-Wave Astronomy Satellite (SWAS) is to be launched on a Pegasus rocket in 1995 or 1996.

34. Probably the most experienced research unit in the field of microsatellites is the Spacecraft Engineering Research Unit at the University of Surrey in the United Kingdom of Great Britain and Northern Ireland. Since 1981, UOSAT and, more recently, the Surrey Satellite Technology Limited (SSTL) team have logged over 25 orbit-years of microsatellite operations. A total of 10 University of Surrey Satellite Project (UOSAT) satellites were launched between 1981 and 1993. The operational microsatellite S-80/T, which is based upon the UOSAT platform, was launched in August 1992 with a mission objective to explore communication possibilities of the very high frequency World Administrative Radio Conference (WARC-92) bands allocated to non-geostationary satellite systems. The initial mission objective has been successfully achieved. S-80/T

completed its first operational year in October 1993 while continuing its flawless functioning. Amateur satellites of the UOSAT series are capable of transmitting images of the surface of Earth, as well as meteorological data.

35. The latest additions to the UOSAT family are a Portuguese satellite (POSAT-1), HEALTHSAT-2 and KITSAT-2, which were launched together in September 1993 aboard Ariane V-59, together with the SPOT-3 commercial remote sensing satellite. POSAT is the result of close cooperation between SSTL Satellite and a Portuguese industrial consortium. KITSAT-2 was built in the Republic of Korea by engineers trained by SSTL. Its platform retains many similarities with S-80/T and KITSAT-1 (launched in August 1992), while some payloads have been developed by engineers of the Republic of Korea.

36. On 9 February 1993, a Pegasus launcher launched the first Brazilian data collection satellite (SCD-1) with an inclination of 25 degrees and an altitude of 750 km. SCD-1, designed and built by the Brazilian National Institute for Space Research (INPE) is a small spin-stabilized satellite dedicated to the collection and distribution of environmental data acquired and emitted by data-collecting platforms over Brazilian territory. Since its launching, SCD-1 has been performing excellently. SCD-2, which is very similar to SCD-1, is now in the final integration stage; it is to be launched early in 1996.

37. The first satellite of an Italian data collection satellite series called the Telespazio Micro Satellite (TEMISAT) was launched by a Russian Tsiklon launcher from the cosmodrome at Plesetsk on 31 August 1993, together with a Meteor-2 satellite. The satellite is orbiting the Earth at an altitude of 950 km and with an inclination of 82.5 degrees and an orbital eccentricity of less than 0.0001. A second unit (TEMISAT-2) was manufactured together with the first one; it is stored on the ground and could be launched to increase the in-orbit service capacity.

38. Applied to Earth observation missions, small satellites can be utilized independently to fulfil the function of specific payload instruments. Several can be flown in a constellation to replace or augment the functions of a larger multi-instrumented satellite. Small satellites will not entirely replace such large platforms, which offer both financial and scientific benefits, such as economies of scale and synergy of measurements. In addition, large satellites are essential where specific instruments must be large enough to achieve their mission objectives with high power and very high data rates (e.g. depending on the size of radar antenna or optical performance on aperture and focal length).

39. Potentially suitable Earth observation missions for small satellites include: global ocean sampling (by a constellation of satellites); geophysical sampling (by a single satellite in polar orbit); ocean and coastal zone colour monitoring; single instrument payload in support of larger missions, commercial mapping and land surveys; crisis and/or disaster monitoring (e.g. floods, forest fires, oil spills), launched on demand or into a constellation; and vegetation monitoring for agriculture and forestry.

40. The recurrent orbit Earth observation satellite project of Japan provides an example of a small satellite that is being used for remote sensing purposes. By using a recurrent orbit (with a repeating ground track every fifteenth revolution), the observation frequency of the area is greatly improved. This is the origin of the Domestic Urban Area Observation Satellite (DUOS) concept.

41. The DUOS system is based on the Optical Intersatellite Communications Engineering Test Satellite, which is currently scheduled to be launched by the J-1 in 1998. It will have a three-axis stabilized bus with two panels of solar arrays and batteries. Within the given mass limit, the satellite could carry the Visible and Near Infrared Radiometer and a thermal infrared radiometer.

42. The long-term goal of the Technical University of Berlin Satellite (TUBSAT) programme is the development of a three-axis stabilized observation platform that can be autonomously oriented to any desired direction with arc minute accuracy. Of primary interest is the remote sensing of Earth, so that precise

stabilization is required both for observation and for a high data transmission rate to permit real-time or almost real-time reception of the pictures. These goals are being approached in several steps.

43. Based on the orbital experience of TUBSAT-A and TUBSAT-B, launched in 1991 and 1994, respectively, instrumentation of the third spacecraft will also include three fibre optic laser gyroscopes. A preliminary structure of TUBSAT-C has already been manufactured and is being used for three-axis air bearing experiments.

44. The pre-operational Fire Reconnaissance System (FIRES), recently studied in Germany, will demonstrate the feasibility and usefulness of a future operational small satellite system for fire reconnaissance. It is anticipated to be of use not only for pure detection of a fire event in large areas, but also for its ability to locate the fire, assess the extent (in space and time) and type of the fire and provide this information to local authorities in a timely manner. In addition to this primary task, the system should be able to solve secondary problems such as assessment of vegetation damage, assessment of atmospheric pollution and evaluation of the revitalization of burned areas. Furthermore, when the satellite is not over vegetated areas, its sensor system can contribute to other remote sensing tasks related to high temperature detection.

45. A satellite health network has been proposed for western Africa by a non-profit agency in the United States, Volunteers in Technology Assistance, using a constellation of small LEO communication satellites to link regional medical centres with village clinics and mobile health teams. Where it would be more economical to do so, two-way radio-telephones would be used to link villages or mobile units to local clinics, which in turn would be linked to a regional centre via satellite. It has been estimated that 10 microsatellites could be built and launched for about US$ 21 million, while about US$ 30 million would be required for the medical facilities and the Earth station network. Such a system could dramatically improve the access of rural people to good medical care. If successful, the experiment would serve as a model for other remote regions.

46. The recent availability of relatively low-cost launch opportunities has made it conceivable for educational institutions to develop, manufacture, test and operate a small satellite. There is always an emphasis on the active participation of members of the university community (professors, students, postgraduates), which gives them invaluable practical experience with space technology and scientific research.

47. For example, the first Spanish microsatellite, UPM/SAT 1, with a mass of 47 kg, has been designed and manufactured by the Universidad Politécnica de Madrid. It is a low-cost platform with a moderately long operational life capable of future evolution. It was launched on 7 July 1995 as an auxiliary payload of the Ariane-40 rocket carrying the French Helios-1A satellite. The main experiment on the satellite comprises monitoring of the behaviour of a fluid configuration called liquid bridge in microgravity conditions. Developing a moderately complex design in a university environment should allow professors and students to get the experience necessary for more complex projects.

48. The Sunset satellite being developed by graduate students in electronic engineering at Stellenbosch University in South Africa is planned for launch early in 1996. It is a microsatellite weighing 50 kg that is compatible with an Ariane launcher and is capable of three-colour stereo imaging of Earth. Pictures can be transmitted in real time or stored on the satellite. The attitude of the satellite can be controlled within 1 milliradian. The communications package includes an S-band downlink and amateur radio store and forward communications with an audio repeater to stimulate radio interest among schoolchildren.

49. The opportunities for small and medium-sized countries to enter into space activities at a relevant level have, in the past, been limited. In the past decade, however, technological advances in materials and microelectronics, together with the experience gained, have allowed many significant space missions to be performed with small satellites. In recognition of the importance of this trend for international cooperation

in outer space, the International Academy of Astronautics, at its meeting in August 1992, elevated the status of its subcommittee on small satellite programmes to the status of a full committee. At the same time, a new subcommittee on small satellites for developing nations was created under the auspices of the committee. It will act as a liaison with the Committee on the Peaceful Uses of Outer Space, the International Space University and the International Astronautical Federation, particularly with its Committee for Liaison with International Organizations and Developing Nations.

50. The long-term goals of the new subcommittee are to promote the use of small satellites for the benefit of developing countries. An assessment of these benefits is made on a regional basis, starting with the situation in Latin America. Each assessment is to be prepared during a workshop organized by the subcommittee with representatives of interested countries. The resulting reports will be published and will serve as a basis for further action. The first regional workshop was held at São José dos Campos, Brazil, on 20 to 23 June 1994 at the invitation of INPE.

51. The eventual success of small satellites and microsatellites is not considered to be in doubt; however, before the full potential of these emerging technologies can be realized, it will be necessary to radically rethink the way missions are specified, realized, funded and operated. The changing role of international cooperation to this effect should be further explored. Because of the diverse nature of both applications and instruments, their needs are unlikely to be met with a common small satellite bus design, but more intensive exchange of experience with different designs could eventually lead to some kind of standardization. The ability to adapt existing hardware readily and cheaply will also be a valuable economic asset for both manufacturer and user.

52. Among the main difficulties in promoting the use of small satellite technology for developing countries is the fact that the countries with established space programmes frequently do not understand the scope of problems within developing countries and that there is a lack of adequately trained local personnel. In this context, it would be extremely valuable if the Committee on the Peaceful Uses of Outer Space would pay more attention to this issue. It is therefore pertinent that the theme fixed for special attention by the Scientific and Technical Subcommittee at its thirty-third session is "Utilization of microsatellites and small satellites for the expansion of low-cost activities, taking into account the special needs of developing countries".

53. Based on the results of its deliberations on this special theme, as well as on recommendations contained in the present report, the Committee might propose some ways and means of ensuring substantial progress in international cooperation in this rapidly developing field. For example, it might recommend that one or more of the educational activities of the United Nations Programme on Space Applications should be devoted to the theme of microsatellites and small satellites.

Notes

[1] *Official Records of the General Assembly, Forty-ninth Session, Supplement No. 20* (A/49/20), para. 29.

Annex

MICROSATELLITES AND SMALL SATELLITES: CURRENT PROJECTS AND FUTURE PERSPECTIVES FOR INTERNATIONAL COOPERATION

Study by the Secretariat*

CONTENTS

		Pages
Introduction		11
I.	Definition of a small satellite	11
II.	Economic aspects of small satellites	12
III.	Orbit selection for small satellites	13
IV.	Possibilities for low cost launching of small satellites	14
V.	Ground support needed for small satellites	15
VI.	Examples of projects using small satellites	16
	A. Small satellites for scientific research	16
	1. Argentina	16
	2. Central Europe	16
	3. Finland	17
	4. France	18
	5. Germany	19
	6. India	19
	7. Spain	19
	8. Sweden	20
	9. United States of America	20
	B. Small satellites for global communication and data collection	21
	C. Small satellites for remote sensing and environmental observations	22
	D. The use of small satellites for disaster monitoring and mitigation	24
	E. Small satellites for national health and health services	25
	F. The use of small satellites for education and training	26
VII.	Possibilities of greater international cooperation in the field of small satellites	27
VIII.	Conclusions	29
List of acronyms		31
Selected bibliography		33

*The present study has not been edited.

INTRODUCTION

1. Small satellites have already been used with considerable success by many organizations. Their attraction lies in the promise of low cost and short development time, which is made possible by the use of proven standard equipment and techniques, together with a realistic expectation of performance. In fact, the space age began with the launching of small scientific satellites during the International Geophysical Year in 1958. At the time, this was due to the limited capacity of the first space launchers. After a modest beginning with small, simple, and lightweight satellites, space systems have evolved into large, complex, and expensive space platforms for scientific research and other applications which often require many years of development prior to launch.

2. While such large platforms exist and will continue to exist, there has recently been a growing interest in returning to the use of small satellites, which can be launched within a few years after programme initiation. As a consequence of the evolution of the state-of-the-art of space-related technologies, this class of spacecraft can make significant space capabilities accessible to a wide number of users, from high school and university students to engineers and scientists in every country in the world. In many ways, small satellite projects are ideal for extensive international cooperation.

3. The development and utilization of small satellites does not replace the utilization of large satellites missions, as the goals and issues involved are often different. Small missions can, however, be a complement to large missions. By exploring new methods and techniques, small satellites can be a pioneering tool for new experiments and technologies for future larger missions.

4. Small satellites have several advantages over large satellites and these hold no matter who the user is: more frequent and larger variety of mission opportunities; more rapid expansion of the technical knowledge base; greater involvement of local industry; and greater diversification of potential users. The small scale factor also means that even a country with a modest research budget and little or no experience with space technology can afford it. Small satellites also represent an excellent method for training students, engineers and scientists in different disciplines, including engineering, software development for on board and ground computers and management of sophisticated technical programmes.

5. Recent technological progress in many areas means that small satellite can offer services previously only available from much larger satellites. Fairly sophisticated scientific and technological experiments, as well as application missions, can be flown in space at modest costs. The areas of application include: space physics, astronomy, astrophysics, technology demonstrations, communications experiments, and acquisition of Earth resource data, including disaster information.

I. DEFINITION OF A SMALL SATELLITE

6. The definition of a small satellite varies, but an upper limit of about 400 kg (exceptionally 500 kg) is usually adopted within which there are two main categories: small (or "mini") satellites of about 100-400 kg, and microsatellites which weigh less than 100 kg. A typical "small satellite mission" (including launch) generally costs less than $20 million and most microsatellite projects cost approximately $3 million.

7. In recent years there have been three main advances in materials and design techniques which have made small- and microsatellites feasible. In descending order of impact in the design of space missions, they are:

- Substantial advances in data handling, processing and storage technologies, as well as, in sensors for attitude determination. This has been achieved by a very large scale integration of components which permits the manufacturing of high performance systems with small size, mass and power consumption.

- More experience in space systems design and new engineering tool and design techniques (CAD, CAM, etc.), which have permitted more reliable and economical systems to be designed.

- Advances in power generation and power storage technologies as well as in propulsion technologies. Future advances in these fields are expected in the medium-term through the use of new types of solar energy generators, and chemical batteries.

II. ECONOMIC ASPECTS OF SMALL SATELLITES

8. A central issue in any small satellite mission will be the optimum balance between programme complexity and risk. Small satellites are likely to offer new opportunities for procurement methods. The selected model philosophies are very important to both risk and cost, and as a maximum, a protoflight approach will be acceptable for such programmes. The advantages of small satellites are:

- orbital parameters are optimized to individual instrument requirements;
- augmentation of conventional satellite programmes, such as additional capability, redundancy for critical missions, or replacement of a failed instrument;
- missions with limited lifetime and/or coverage requirements;
- improved responsiveness to the end user (more frequent launch opportunities and increased mission flexibility for individual instruments, plus schedule independence);
- quick reaction/launch-on demand launches using low-cost dedicated vehicles, e. g. crisis monitoring, replacement after an on-orbit failure, or monitoring of unexpected environmental conditions;
- relaxed reliability due to the shorter lifetime or agreed, lower levels of product assurance or lower quality parts as appropriate to lower development costs; and
- reduced satellite design complexity (e.g. simplified interfaces, optimized for instrument requirements), shorter development schedule and suitable test-bed for technique/technology proving.

9. However, superior but still economical alternative approaches might be possible in cases where several flight spacecraft are to be produced (successive launches in intervals, constellations, etc.). In such cases, further potential benefits will be available, such as:

- batch production of components and elements;
- "learning" benefits in properly-phased repeated production;
- optimization of test activities (e.g. batch testing);
- minimize facility occupation times;
- minimize GSE requirements and quantities; and
- minimize of programme duration.

10. In principle, a small satellite bus providing a clean physical interface for payload mounting could equally well carry a single large instrument or a number of smaller ones within the same envelope and resource allocation. Using typical and very approximate figures for small satellite programmes in Europe, a budget of 150 Million Accounting Units (MAU -about $200M) over two years could allow a 400 kg class of spacecraft to be launched each year in a long-term programme. The development time to launch a small satellite would typically be three years and the mission life of such a satellite is roughly 2-3 years.

11. The two most often quoted areas for cost reduction on small satellite programmes are the areas of programme management procedures and product assurance requirements, but technical areas may also offer potential. In the programme management area, measures include limiting the geographical distribution of work in order to minimize formal and effort-intensive interfaces between contractors; co-locating a core team of several contractors covering the system design and specification aspects of each programme; and including

payload specialists, so that interaction and compromise between payload requirements and spacecraft provisions can take place.

12. In the technical area, examples of possible sources of cost reduction include designing the systems to lower reliability targets than usual, the possibility of architectural integration between payload and satellite and across satellite subsystems to permit failure recovery by reconfiguration rather than simple functional redundancy, and electronic solutions to system design instead of mechanical ones wherever possible (e.g. image stabilization).

13. Some of the key design elements for developing a small satellite infrastructure can be summarized as follows:

- Standardization of satellite bus and support services, to reduce high non recurring costs and allow for quantity buys of parts and components;
- Standardization of systems, using "off-the-shelf" systems or subsystems that can be incorporated into a spacecraft design, adding significant capability at little incremental cost;
- Utilization of the latest technology, especially electronics, substantially increasing the useful mass ratio of the satellite;
- Design with satellite autonomy as a key feature, to eliminate the costs of significant ground support, and to minimize ground-to-space contact and command-and-control complexity;
- Apply quality assurance practices consistent with the satellite mission (short duration, relatively low cost, acceptable risk of failure), using cost-effective systems which still meet mission goals;
- Resist the escalation of requirements which will drive the satellite design to ever-increasing levels of complexity and sophistication, forcing the mass, power and cost of an (intended) small system to that of a heavy, complex and expensive satellite; and
- Approach the development from a system perspective, viewing the satellite system as a whole, maintaining a balance of requirements among segments of the system cost, launch, on-orbit operations and required information gathering and transmission.

14. The advantages of small satellite projects usually include: a small development team (usually with one or two contractors); short development cycle (usually only a few years); and the satellite is designed to perform relatively few tasks (usually only one).

III. ORBIT SELECTION FOR SMALL SATELLITES

15. There are three general classes of orbits which may be suitable for small satellites: the Geostationary Earth Orbit (GSO), Highly Elliptical Orbits (HEO) and Low-Earth Orbits (LEO).

16. The GSO is where the satellite appears fixed relative to the ground, thus allowing continuous visibility and therefore simplifying the ground segment and operational requirements. However, because of the large space-to-ground distance involved, the data rates would be small, or larger ground antennas and higher electrical power on board the spacecraft will be required. This orbit is usually reached from a standard Geostationary Transfer Orbit (GTO) provided by a large launch vehicle. The circularization of the orbit from the GTO to GSO will require an apogee propulsion system which would roughly double the mass of the satellite at launch. Small launchers will not usually offer enough performance for such missions.

17. The use of a GTO itself is an interesting derivative which could benefit from frequent piggyback launch opportunities, but avoid the complexity and extra costs associated with the apogee propulsion system.

18. Small satellites may by put into HEOs such as orbits inclined at 63.4 degrees. Such orbits are particularly attractive, because the plane is unaffected by the flattening of the Earth, thus it remains

practically fixed in a geocentric inertial reference frame. Certain launchers (e.g. Russian Molniya launcher) are able to deliver satellites into HEO orbits, thus simplifying or obviating the need for an on board propulsion system. High-eccentricity fixed orbits allows minimization of the number of satellites covering certain desired areas which remain visible for long periods of time. This obviously has advantages for telecommunication satellites, but it is not particularly useful for remote sensing missions. As for the GSO, this orbit is not very compatible with assumptions of low mass and low-cost satellites.

19. LEO is generally preferred for small satellite missions. Small launch vehicles can be used, offering flexibility in the selection of the orbit parameters, or piggyback launches may be available. A low energy on board transmitter is sufficient because of the short distance from the ground, but infrequent and short visibility periods are a drawback which will lead to some ground segment and operational complexity. One should also distinguish between the near equatorial or low inclination orbits for which the visibility zone will be limited to the topical zone, and the polar and quasi-polar (Sun-synchronous) orbits which allow accessibility to any point on Earth, either for communication (e.g. store and forward) or for remote sensing of the Earth.

IV. POSSIBILITIES FOR LOW COST LAUNCHING OF SMALL SATELLITES

20. The current and future development of small satellites is closely linked to the appearance of new, low-cost launchers (such as the United States Pegasus, Taurus, etc.) and lower cost launch opportunities on existing vehicles (for example Ariane-4 or small canisters on the Space Shuttle). Indeed, the potential availability of cheap launchers has spurred much of the recent surge of interest in small satellites which was initially largely driven by United States defence and global civil communication programmes. Of the major European and United States low-cost launchers, only Pegasus and Taurus are flight-proven. Conestoga is planned for flight in the near future, development of the Italian San Marco Scout (SMS) has not yet started (although its forerunner, the United States Scout, has been operated for many years), and the Ariane-5 derivative programme which should be completed in 1999.

21. In order to maximize their potential, small launcher developers must apply the same innovative, low-cost design approach used on small satellites. Launch costs represent a large fraction of total programme costs (generally over 25 per cent) and satellite mass and size must therefore be constrained to take full advantage of low-cost launch opportunities. Options include:

- Small dedicated launchers;
- Multiple launch of several small satellites, nominally on Ariane-4 or -5 for European missions (e.g. ESA's Cluster scientific satellites);
- Flight opportunities on larger launchers. Arianespace has strongly promoted its vehicles for this purpose, with Ariane-4 offering: ASAP for "piggy-back" microsatellites (200 kg total, up to 6 x 50 kg satellites); ARSENE-type configuration for satellites up to 200 kg; and SDS for satellites in the 400-800 kg range within the short SPELDA adapter).

22. Similar options are provided by other medium or large launchers, for example the United States Atlas Centaur and the Delta-2. However, small satellites launch opportunities are relatively rare, because resources (mass/volume etc.) are limited and mission parameters and schedule are generally dictated by the main user. The design drivers used when evaluating launcher capabilities against satellite requirements are well known. These include: the available accommodation inside the launcher fairing (this is often a greater constraint than payload to orbit mass capability); the suitability of specific launch site locations for the required altitude and inclination; the cost; the need for a launch on demand capability which, if required, has enormous operational impact (typical surveillance missions may have notification requirements of less than one week).

23. A spacecraft owner needs to assess each launch vehicle option with respect to the following considerations prior to making a launch vehicle selection decision. The most important consideration being the spacecraft value, an assessment of the profit potential and the costs associated with its replacement. A second consideration should be the potential launch vehicle's reliability record or flight history. A series of low-cost payloads may be willing to take the risk of a new lower-cost launch vehicle with an unproven record. Once a commitment is made to a particular vehicle, the spacecraft and its payload will typically require some modifications if it is necessary that it be launched on a vehicle different from the one for which they were originally designed.

V. GROUND SUPPORT NEEDED FOR SMALL SATELLITES

24. Requirements for the ground segment of a small satellite system will vary enormously depending on the application area. At one extreme, low data rate sensors with only local or regional coverage on missions with low tracking and command requirements will impose relatively low demands on the ground segment, possibly comprising only 10 per cent or less of total programme costs. More complex data retrieval and processing requirements could result in ground segment costs of up to 50 per cent of total programme costs. Assuming that ground segment costs tend to average 25 per cent of the programme total, it is clearly important to identify potential savings in the ground segment in concert with those of the space segment.

25. Specific features of small satellites which can be exploited in the ground segment to save costs include: "lower" specifications (as increased risk is acceptable); smaller teams, implying fewer interfaces; and less complexity (restricted objectives), fewer communications channels etc.

26. However, in attempting to reduce the ground segment costs, there are limits on simplification because it is still necessary to ensure the achievement of capabilities such as reliable operation, rapid response to critical commands and regular form of data on time and with low loss. The ground segment model which forms the basis for any technical and cost assessments must include not just the provision of the ground stations but also ground communications infrastructure, mission control, etc. Recently there is also a possibility to use very small stations, in some cases transportable, which are available commercially from several United States and European suppliers. Commercial providers of remote sensing data are likely to press for the adoption of such approaches in attempts to reduce the cost of distributing and processing the data.

27. An important factor in effective implementation of any small satellite project is the need to provide low-cost space-to-ground communication system. Most ground stations are designed to ensure that a complex spacecraft will operate over many years and therefore they have redundancy, self-test functions, and sophisticated capability built- in. A small satellite ground station does not need the same level of capability and could be optimized for the low cost satellite mission. Such a ground station is usually composed of satellite command, control, and monitoring systems as systems for reception of payload data signals. The satellite command and monitoring process is called telemetry, tracking and control (TT&C). The telemetry aspect of space-to-ground communications involves the collection, transmission, and reception of satellite configuration and status data that characterizes the satellite's operation. The tracking aspect determines the satellite ephemeris (position and velocity predictions) through distance, velocity, and antenna pointing angle information. The command element generates commands for remote control of the satellite and often the payload it carries.

28. The typical satellite ground station is composed of five principal elements: the antenna subsystem, the command (uplink) subsystem, the telemetry (downlink) subsystem, the monitoring and control subsystem, and the data processing subsystem. The degree of separation between these subsystems is dependent on the system architecture. The capability, complexity, and robustness of a satellite ground station are determined by a system engineering study in which technical and cost issues are compared and an optimized design for

the mission is produced. Therefore, while the basic elements of a station are common, there is a great deal of variation in the actual design based on the tradeoffs made in the system engineering study.

29. In addition, small satellites are likely to be the cause of major changes in ground systems design and operation because of their new cost-performance characteristics. For example, a major consideration is a potentially significant increase in the number of spacecraft to be controlled. This may result in an increase of the number of missions that can be afforded as well as the use of a constellation of spacecraft to meet the requirements of a single mission.

VI. EXAMPLES OF PROJECTS USING SMALL SATELLITES

A. Small satellites for scientific research

30. Space science activities are obviously valuable, and most space-faring nations have begun their involvement in this field with small scientific satellites. A university environment is often an ideal environment for development of space activities and because such projects often require the creation of new laboratories, these facilities are a lasting, beneficial byproduct of such projects. Thus the usual spin-offs of a space programme, the acquisition of technology and development of industrial organization and management methods, will begin to accumulate at the national level as students leave the university and enter local industry.

31. The following are some examples of small scientific satellite programmes that have been successfully developed. Emphasis is placed on recent programmes of countries with small or modest space programmes.

1. Argentina

32. Argentina's first small scientific satellite will be the SAC-B (Scientific Applications Satellite) which is being developed jointly by Argentina's national space agency, Comision Nacional de Actividades Espaciales (CONAE) and the National Aeronautics and Space Administration (NASA) of the United States. The 190 kg satellite should be launched in 1996 by a Pegasus rocket into a 550 km circular orbit with an inclination of 37 degrees. SAC-B will be inertially stabilized and permanently oriented to the Sun. It will monitor energetic X-rays from solar flares and survey the sky with X-ray CCD sensors along an axis perpendicular to the Sun line. Due to the seasonal motion of the Sun relative to the sky, the 3 x 3 degree detector will scan the entire sky during one year. The design life of the satellite is three years.

2. Central Europe

33. Between 1978 and 1991, scientific micro-satellites weighing 15-50 kg were developed for the Magnetosphere-Ionosphere (MAGION) research programme in the former Czechoslovakia. MAGION-1 was launched on 24 October 1978 as a subsatellite of the INTERCOSMOS-18 geophysical satellite and although it was designed for an operation lifetime of three weeks, it remained operational for three years later. MAGION-2 and MAGION-3 were launched into high-inclination low-eccentricity orbits (altitude 500-3,200 km) as a part of the ACTIVE and APEX mother-daughter active space experiment missions launched 28 September 1989 18 December 1991, respectively. The payload of the subsatellites was used as an independent diagnostic package. During periods when no active experiments were switched on, the satellite and subsatellite were used for simultaneous two-point measurements of natural magnetospheric phenomena.

34. Two more sophisticated MAGION-type subsatellites have been designed for the INTERBALL mission which will study physical mechanisms of solar wind energy accumulation in the magnetosphere and dissipation of the energy in the auroral regions during magnetic substorms. The INTERBALL mission consists of two pairs of spacecraft, situated in different orbits: one pair, the Auroral Probe with an apogee

of about 20,000 km; the other one, the Tail Probe, with an apogee of 200,000 km. Both orbits should have perigee heights of about 500 km and inclinations of 65 degrees. Each pair of satellites consists of the main spacecraft of the PROGNOZ series, accompanied by a subsatellite of the MAGION type. The scientific objectives for the subsatellites are to separate time and space variations, to study spatial correlations and fine structures in the ionosphere and magnetosphere. Separation of the subsatellites will be controlled by small thrusters. The INTERBALL subsatellite payload and subsystems have been developed and manufactured through an international cooperative effort involving Austria, the Czech Republic, France, Germany, Poland, Slovakia, Romania and the Russian Federation. The MAGION-4 subsatellite was successfully launched by a Molniya launcher from the Russian cosmodrome at Plesetsk on 3 August 1995, as part of the INTERBALL-tail mission and MAGION-5 is currently scheduled for a 1996 launch.

35. The Central European Satellite for Advanced Research (CESAR) is a spacecraft of about 300 kg that will fly in an orbit with a 400 km perigee, 1,000 km apogee and 70 degree inclination. The scientific mission is related to the study of the magnetosphere, ionosphere and thermosphere (MIT) Earth environment. Ten different experiments, provided by scientists from Austria, Czech Republic, Hungary, Poland and Slovakia will be accommodated on the spacecraft which is funded by the Italian Space Agency, ASI, and designed by Alenia Spazio. This mission is one of the objectives of the cooperation among the countries of the Central European Initiative (CEI).

36. A feasibility study for CESAR has been started and a detailed technical study funded by ASI will be conducted by Alenia Spazio concerning the spacecraft's system engineering. The participating countries will develop the experiments they are responsible for and will collaborate with each other regarding on board accommodation for the experiments.

37. The nominal mission lifetime will be two years which will allow a sufficient period of observation of the complex MIT phenomena. The evolution of the initial orbit will be determined by the natural perturbations since no propulsion capability is provided on the satellite. The once-per-orbit perigee-apogee excursion, combined with the slow procession of the orbital plane with respect to the Sun and the Earth, will provide the payload with complete sampling of the near-Earth environment between 400 and 1000 km and ±70° latitude in all conditions of illumination over lifetime of the mission.

38. The spacecraft should be launched by direct injection into its required orbit by a small launcher (either an improved Scout or Pegasus). Deployment of the solar array and S-band antennas will follow separation. The spacecraft will be attitude stabilized by spinning around a sun-pointing axis with a rate of 4 rpm. The spin rate will provide the experiments with a fast scan and sampling of the environment surrounding the spacecraft. Boom mounted experiments will be deployed after attitude acquisition. About one month of spacecraft commissioning and experiment calibration will follow. After the nominal operation of the satellite has been certified, the science mission will be carried out for the following two years.

39. The present configuration foresees a mass budget with about 151 kg of service module and 95 kg of payload module for an operative launch configuration mass of 246 kg. A mass margin of 20 per cent is accounted for in the next phase to take into account increases that will surface during the development process. The spacecraft is expected to be completed before the end of 1997 for a launch at the beginning of 1998. CESAR will be the first spacecraft of a series that will also included a second spacecraft currently in preparation, the Joint Ultra Violet Night Sky Observer (JUNO) a UV astronomy satellite being developed in cooperation with NASA. A definition phase study for JUNO is underway.

3. Finland

40. Finnish space industry and research institutions have gathered experience in satellite payloads and instrumentation through their associate membership in the European Space Agency, and have long been active in remote sensing and other space related disciplines. Because Finland does not have experience in satellite

bus development, conducting a small satellite development programme represents a technological leap for the Finnish space industry. The experience gained through such a programme could later be used in bigger satellite programmes. To initiate a study of a Finnish Small Satellite (FS-1), Finnish institutes defined their interests by contacting selected institutes with an unofficial Announcement of Opportunity, and by asking for proposals. After the proposal phase, system design was performed for two alternatives: a scientific satellite and Earth observation satellite. Both satellites would contain a technology demonstration package, in which new electronic components would be tested in the space environment.

41. The payload of the Science Mission (FS-1/SCI) is essentially as proposed by the Finnish Meteorological Institute. The mission is configured to study the fundamental physical processes in the low altitude and high latitude plasma environment of the Earth. The concept includes a polar orbiting satellite (altitude 1,200 km, active lifetime of 1 year) and a large number of ground facilities in the northern polar region. The launch mass of the satellite is 150 kg, including 44 kg of scientific payloads (magnetic field sensors, electrical field sensors, charged particle detectors and component test experiment). The satellite design is a spinning body with electric and magnetic sensor booms and body mounted solar cells. The spin axis should be roughly parallel to the Earth axis.

42. The possible Earth observation mission (FS-1/EO) is optimized to such a single objective, which is not well covered with present Earth observation satellites. Such special objectives are full coverage forest inventory, mapping of sea ice, or a demonstration of a new instrument, for example a 90 GHz radiometer or spectral imager. The satellite design in this case should be a three-axis stabilized body in a polar sun-synchronous orbit (altitude 600 km, active lifetime 2-5 years). The schedule from the start of the phase B (definition) to the launch (probably by a Pegasus launcher) is proposed to be four years.

4. France

43. The French space agency CNES is currently considering the following small scientific satellites:

44. Mission SAMBA: registration of the local fluctuations of 3K radiation from the Big Bang (similar to the United States COBE satellite) and detailed measurement of possible anisotropies. It will use a 55-mm telescope and bolometer, two helium reservoirs for two years of operation, sun-synchronous orbit at 800 km, inclination of 98 degrees, all sky survey except polar regions. The expected mass of the satellite is 120 kg, and planned electrical consumption is 180 W.

45. Mission COROT: astroseismology, new data on the convection and internal rotation of stars by long-term measurement of stellar oscillations. It will study three stars of the F or G type, 4-6 magnitude for 18 months. Planned instrumentation will include a telescope and photomultiplier with a 2 degree field of view, capable of registering light oscillations in a frequency range of 1000 - 5000 μHz with relative accuracy of 2.5 ppm. The mass of the satellite is expected to be about 50 kg, and planned electrical consumption is about 45 W.

46. Mission IBIZA: registration of the plasma accelerated in the geomagnetic auroral regions, interaction of ionized particles with the Earth ionosphere and magnetosphere, creation of electromagnetic disturbances. Two satellites will be launched, both for two years, (similar to the MAGION and CLUSTER programmes). The preliminary mass estimate is 70 kg and power consumption is projected to be 80 W.

47. QUICK-STEP: verification of the equivalence of the inertial and gravitational mass (theory of relativity) with relative precision of 10^{-17}. Instrumentation is based on the measurement of displacement of two masses and will require a liquid helium cryostat. Expected mass is about 400 kg, and planned electrical consumption is 120 W.

5. Germany

48. On 3 February 1994, the University of Bremen's small satellite, BREMSAT, was carried into orbit by the United States Space Shuttle Discovery. The 63 kg spacecraft waited six days in its Get Away Special (GAS) container before it was deployed into its initial 350 km circular orbit. Its 57 degree orbital inclination was chosen to enable its operation from the ground station at Bremen's drop tower. The satellite was designed, developed and tested by a private company under contract from the German Space Agency, DARA, during a three year period. The satellite carried six experiments with different scientific objectives, including heat conductivity under microgravity, micrometeorite and dust particle distribution, atmospheric atomic oxygen mapping and re-entry pressures and temperatures. The satellite functioned until its in-orbit decay on 12 February 1995.

6. India

49. In the process of the development of its indigenous launching capacity, India prepared a series of small technology development and scientific satellites called Rohini (RS) and Stretched Rohini Scientific Satellite (SROSS) series. The RS satellites were launched between 1980 and 1983 and carried a landmark sensor payload including a solid state camera. More than 2,500 frames in both visible and infrared bands for identification of landmarks and altitude and orbit refinement were obtained. The orbital mass of the RS satellites was about 42 kg.

50. The SROSS satellites were primarily designed for conducting experiments in space sciences, space technology and applications. The mass is around 150 kg and their modular design can accommodate a variety of payloads in the range of 15-35 kg. The design also allows the spacecraft to be operated either in the three-axis stabilized mode or in the spin stabilized mode. The spacecraft is octagonal prism shaped with both body-mounted and deployable solar panels on all sides. The structure is made of a special aluminum alloy with honeycomb construction for the decks.

51. The SROSS-C and SROSS-C2 satellites were launched on 20 May 1992 and 4 May 1994, respectively. They both carried two scientific payloads. The first is the Retarding Potential Analyzer, consisting of two planar detectors to measure plasma parameters and to investigate energetic structure of the equatorial ionosphere. The Gamma Ray Burst Experiment consists of two scintillation detectors to study celestial gamma-ray bursts in the energy range of 20 keV to 3000 keV.

7. Spain

52. The National Institute of Aerospace Technology of Spain (INTA), located in Torrejón de Ardoz, Madrid, has been entrusted by the Spanish government with the direction of a research project for the development of a Spanish space system, called MINISAT. The system will consist of a multipurpose platform (service module), payload module and an associated ground segment. Both the platform and the subsystems comprising it are modular in character. The platform will be capable of receiving, integrating, operating and carrying on-board a payload module by means of standard interfaces. This will permit all the required adaptations for a particular mission to be easily conducted. The platform will be able to carry payloads with masses that vary between 80 and 500 kg. The first of these satellites will be the MINISAT mission carrying the PLM-1 (pay load module).

53. This first mission will be for promotional purposes. From among the different possibilities, three technological experiments have been selected. They comprise the measurement of the background radiation in the extreme ultraviolet range, the experimental construction of a new generation of gamma telescope and studies of the deformation produced in a liquid column under different accelerations within the microgravity range. In accordance with the technological and experimental requirements, the PLM-1 satellite will have an approximate mass of 90 kg and will be injected into LEO at an altitude of 600 km, with an inclination

28.5 degrees. The satellite has a planned lifetime of two years. The detail design phases (C2 and D) of MINISAT development were to be completed in 1995 and satellite launch was planned for 1995/1996 period.

8. Sweden

54. The first Swedish-built satellite was the 283 kg Viking which was launched into low polar orbit in 1986 in a piggyback configuration with France's SPOT remote sensing satellite. The scientific objective of the Viking satellite was to study ionospheric and magnetospheric phenomena at high geomagnetic latitudes in the altitude region up to about two Earth radii. Simultaneous measurements were made of electric and magnetic fields, particle distributions, plasma composition and waves as well as imaging in the ultraviolet of the aurora variations.

55. A more advanced small scientific satellite, called Freja, was launched on 6 October 1992 by a Chinese launcher. This 214 kg satellite is designed for auroral research and other related magnetospheric phenomena. The Freja payload consists of a full complement of high-resolution plasma diagnostic instruments and a fast auroral imager. Scientific experiments were also supplied by Germany, Canada and the United States of America. Due to the high telemetry rate and novel design of the instrumentation, which enables more than an order of magnitude higher temporal/spatial resolution compared to its predecessor, Freja is exploratory in many ways. In order to cut costs, only one satellite was built and the protoflight model was first used for all qualification tests, and then for the actual flight.

56. Satellite data are received at ESA's European Sounding Rocket Launching Range (ESRANGE) in Kiruna and at the Prince Albert Satellite Station in Saskatchewan, Canada. Commands for transmitting data and for switching experiments on and off are executed from ESRANGE. The satellite has a stored-command capability in order to operate over Canada without a real-time command link. Full-scale scientific data operations began in late October 1992. Full-scale operations of Freja were planned for two years. The next planned Swedish scientific satellite is called Odin. It will be devoted to spectroscopic studies at sub-millimetre wavelengths of astronomical objects and processes in the Earth atmosphere. Odin is planned to be a multilateral mission that will be launched in 1997 at the earliest.

57. Because Swedish magnetospheric scientists are very interested in the possibilities of small satellites, a compact satellite platform has been developed which is 10 per cent of the mass of the Freja. This new micro-satellite, called Astrid, is the size of a 50 cm box and has mass of 25 kg in its stowed configuration. It is spin-stabilized with a sun pointing capability and deployable solar panels. The first Astrid was launched on 24 January 1995 from the Plesetsk cosmodrome in the Russian Federation on a Cosmos launcher. It carried experiments from the Swedish Institute for Space Physics in Kiruna for monitoring the distribution of energetic particles in the magnetosphere. The launch of the Astrid-2 microsatellite with magnetospheric experiments from the Royal Institute of Technology in Stockholm is expected to take place in 1996.

9. United States of America

58. The best example of the small satellite programmes in the United States is NASA's Small Explorer Program (SMEX), which provides for frequent flight opportunities for highly focused and relatively inexpensive science missions. Small Explorer spacecraft weigh approximately 250 kg and each mission is expected to cost approximately $50 million for design, development and 30 days of in-orbit operations. The first satellite of this series, the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX) was launched on 3 July 1992. It has been successfully investigating the composition of local interstellar matter and solar material, and the transport of magnetospheric charged particles into the Earth atmosphere. The Submillimeter Wave Astronomy Satellite (SWAS) was scheduled for launch on a Pegasus rocket in 1995 or 1996 period. SWAS will for the first time directly measure the amount of water and molecular oxygen in interstellar clouds, and it will also measure carbon monoxide and atomic carbon which are supposed to be major reservoirs of carbon in these clouds. Another satellite, the Fast Auroral Snapshot Explorer (FAST)

should be launched one month after SWAS to probe the physical processes that produce aurorae in the upper atmosphere at high latitudes.

59. An addition, two missions have recently been selected for design, development and launch by Pegasus launchers in the 1997-1998 timeframe. The Transitional Region and Coronal Explorer (TRACE) will observe the Sun to study the connection between its magnetic fields and the heating of the solar corona. The scientific team for this project will include scientists from the Netherlands, Sweden, the United Kingdom of Great Britain and Northern Ireland and the United States. The second spacecraft, the Wide-Field Infrared Explorer (WIRE), will use a cryogenically cooled telescope and arrays of highly sensitive infrared detectors to study the evolution of galaxies.

B. Small satellites for global communication and data collection

60. Advanced satellites that can handle the high data rates needed for real-time, high-quality video and data communications offer unique advantages, for example:

- Mobility. As compact personal communications become more common, users will expect the same access to telecommunications networks from remote areas;
- To supplement and provide back-up for ground based communications; and
- To collect data from widely dispersed in-situ sensor networks that continuously monitor the natural environment with possible concentration on hazardous areas.

61. The amateur radio community has pioneered the use of small satellites for communications. The first of a series of small "ham radio" satellites, the 4 kg OSCAR-1, was launched in 1961 as a piggyback payload on the Discoverer-36 defence satellite. The subsequent satellites in this series, OSCAR 3-8 had greater masses (15-30 kg) and more sophisticated instrumentation which allowed highly reliable amateur radio experiments to be conducted. While the satellites of this type had been initially launched into LEO, recent systems use HEOs or GTOs and plans are even being developed for some GSO positions.

62. Probably the most experienced research unit in the field of microsatellites is the Spacecraft Engineering Research Unit (UOSAT) at the University of Surrey, United Kingdom. Since 1981, UOSAT and, more recently, the Surrey Satellite Technology Ltd. (SSTL) team, have logged over 25 orbit-years of microsatellite operations. There were a total of 10 UOSAT satellites launched between in 1981 and 1993. The operational microsatellite S-80/T is based upon the UOSAT platform and was launched in August 1992 with a mission objective to explore communication possibilities of the VHF WARC-92 bands allocated to non-geostationary satellite systems. The initial mission objective has been successfully achieved and S-80/T completed its first operational year in October 1993 while continuing its flawless functioning. Amateur satellites of the UOSAT series are capable of transmitting images of the Earth's surface as well as meteorological data.

63. The latest additions to the UOSAT family are POSAT-1, HEALTHSAT-2 and KITSAT 2 which were launched together in September 1993 aboard Ariane V-59 along with the SPOT-3 commercial remote sensing satellite. POSAT is the result of a close cooperation between SSTL and a consortium of Portuguese industry. POSAT carries a range of communications, small scale space science, technology demonstration and Earth observation payloads, which, together with an enhanced bus system, make it one of the most sophisticated of the latest generation of microsatellites. KITSAT-2 was built in the Republic of Korea by SSTL-trained engineers. Its platform retains many similarities with the S80/T and KITSAT-1 (launched in August 1992) while some payloads have been developed by Korean engineers. Similarly, the newest SSTL microsatellite FASAT-ALFA, launched on 31 August 1995, was intended to be the first Chilean satellite. It carries 300 Mbytes of SRAM, an Earth imaging camera (with 80 m resolution), an ozone camera and four radiometers for studying the ozone hole, digital store and forward communications using advanced on board data processing and a 3-axis stabilization reaction wheel system. Unfortunately, it has not separated from the main SICH satellite.

64. Part of the reason for UOSAT's success is the remarkably short project time scale and comparatively low project costs that have been achieved. A UOSAT microsatellite mission can be completed within 12 months from contract initiation to in-orbit delivery, enabling a rapid response to the customer's requirement. Time scales are kept short and costs low by the adoption of small-team techniques and a high degree of modularization within the satellite bus and experiments. Technologically, UOSAT has prospered from increasingly widespread availability of low power CMOS processors and memory. While UOSAT was launched with a generous (by 1981 standards) 128k bytes of memory and two on board computers, the latest UOSAT class microsatellites may contain as many as ten computers with up to 48 M bytes of memory. With the exception of the S80/T microsatellite (which operates in a 1,300 km, 66 degree inclined orbit), all UOSAT spacecraft have been approximately 800 km sun synchronous orbits (inclination of approximately 98 degrees). The relatively low radiation dosage, below the Van Allen belts, has allowed the designers to take unconventional approach of using conventional computers and other essentially "off-the-shelf" terrestrial hardware.

65. The use of small satellites for communications is a very complex question and is discussed in detail in separate studies (e.g. A/AC.105/536 "Applications of space technology for remote and rural communications and broadcasting", and A/AC.105/564 "Use of low Earth orbit satellites for voice communications"). For the present study, emerging systems of data collection and distribution by small satellites are worth mentioning.

66. On 9 February 1993, the first Brazilian satellite, SCD-1, was launched in its 25 degree inclination orbit at 750 km altitude by a United States Pegasus launcher. The SCD-1 satellite, designed and built by the Brazilian National Institute for Space Research (INPE) is a small spin stabilized satellite dedicated to the collection and distribution of environmental data acquired and emitted by data collecting platforms distributed over Brazilian territory. Since its launching, the SCD-1 has been performing excellently. A second satellite (SCD-2), very similar to the first one, is now in the final integration stage, to be launched in early 1996.

67. To continue its space programme, INPE is now developing the SCD-3 satellite. It is a small, 200 kg three-axis stabilized satellite that will be injected into a 750 km high equatorial orbit. The mission of the SCD-3 is divided in two parts: environmental data collection and in-orbit testing of a LEO communications system, the ECO-8, also being developed in Brazil. The SCD-3 data collection payload is similar to that of its predecessors but will offer an improved service due to its Earth-pointing orientation and the inclusion of an additional UHF transmitter which allows DCP users to receive the data directly from the satellite by means of a small receiving station coupled to a personal computer. The SCD-3 communications experiment consists of an L/S-band transponder that permits voice communication between small portable terminals through a gateway station. The terminals access the satellite through CDMA and the Alcantara Earth station in northeastern Brazil is used as the gateway.

68. An Italian data collection satellite series is called the Telespazio Micro Satellite (TEMISAT). The first satellite was launched by a Russian Tsiklon launcher from Plesetsk Cosmodrome on 31 August 1993 along with a Meteor-2 satellite. The satellite is orbiting the Earth at 950 km altitude with an inclination of 82.5 degrees, and an orbital eccentricity less than 0.0001. A second unit (Temisat-2) was manufactured together with the first one; it is actually stored on the ground and could be launched to increase the in-orbit service capacity. These are professional microsatellites which, for the first time, adopt for commercial application a low cost satellite-based TDMA/SCPC access scheme. The service offered will be dedicated to data collection and distribution for autonomous networks.

C. Small satellites for remote sensing and environmental observations

69. Remote sensing camera systems can view the Earth and can be used to gather both weather and land data that can help to identify a country's resources and provide early warning of natural disasters. Such systems can also be used to monitor borders, evaluate crops and predict their yield, and improve mapping accuracy. Small satellites are ideal for environmental studies, monitoring biological reservoirs, rain forests,

marine habitats and the progress of the mass destruction of living species and renewable natural resources. They can also be used to provide countrywide surveillance of illegal activities, including those in inaccessible land and ocean areas.

70. Applied to Earth observation missions, small satellites can be utilized independently to fulfil the function of specific payload instruments or several can be flown in a constellation to replace or augment the functions of a larger multi-instrumented satellite. It is clearly not the case of small satellites entirely replacing such large platforms, where considerations such as "economy of scale" and synergy of measurements offer both financial and scientific benefits. Additionally, large satellites are essential where specific instruments must be large enough to achieve their mission objectives, with high power and very high data rates (e.g. depending on the radar antenna size, or optical performance on aperture and focal length).

71. Potentially suitable Earth observation missions for small satellites include: global ocean sampling (by a constellation of satellites); geophysical sampling (by a single satellite in polar orbit); ocean and coastal zone colour monitoring; single instrument payload in support of larger missions, commercial mapping and land surveys; crisis/disaster monitoring (e.g. floods, forrest fires, oil spills), launched on demand or into a constellation; and vegetation monitoring for agriculture and forestry.

72. Japan's recurrent orbit Earth observation satellite project is an example of a small satellite that is being used for remote sensing purposes. Japan is an island country which stretches to northeast and southwest like a bow. Approximately 70 per cent of its land mass is mountainous and most of its population is concentrated in coastal areas. Because of its unique geographical properties, it takes 24 and 16 days, respectively, for the SPOT and LANDSAT remote sensing satellites to observe Japan's main islands. However, it can be understood that the urban area is placed upon a belt faced along the Pacific Ocean. This belt could be covered by just one path of a satellite in an orbit with an inclination around 35-40 degrees. By using a recurrent orbit (with a repeating ground track every 15th revolution), the observation frequency of the area is greatly improved. This is the origin of the Domestic Urban Area Observation Satellite (DUOS) concept. The launch vehicle for this project is the J-1, which is under development by NASDA with a first test flight scheduled for 1996. The launch capability of the J-1 is a payload of 500 kg into a circular orbit with an altitude of 500 km and an inclination of 30 degrees.

73. The DUOS satellite system is based on the Optical Intersatellite Communications Engineering Test Satellite (OICETS) which is currently scheduled to be launched by the J-1 in 1998. It will have a three-axis stabilized bus with two panels of solar arrays and batteries. Within the given mass limit, the satellite could carry the Visible and Near Infrared Radiometer (VNIR), a thermal infrared radiometer (TIR) and a SAR system. However, SAR requires large amounts of electric power which exceeds the capacity of DUOS. Therefore, only the VNIR and TIR instruments are available for this domestic area observation system. A swath width of 150 km is generally necessary to cover an urban area. The number of observation bands, spatial resolution and other parameters must be a trade-off inside the range of data rate by X-band transmission. For continuous observation, two satellites should be operated with the local time difference of 12 hours.

74. The long-term goal of the Technical University of Berlin Satellite (TUBSAT) programme is the development of a three-axis stabilized observation platform that can be autonomously oriented to any desired direction with arc minute accuracy. Of primary interest is the remote sensing of the Earth, so that precise stabilization is required both for observation and for a high data transmission rate to permit real time or almost real time reception of the pictures. These goals are being approached in several steps.

75. The first satellite, TUBSAT-A was launched on 17 July 1991 by Ariane V44 as a secondary payload with the first European Resource Satellite. It is a cube with mass of 35 kg and its attitude is not yet controlled, but very accurately determined by a gyro and magnetometer sensors. After more than four years in orbit, TUBSAT is still completely operational. The only degradation has been the loss of 50 per cent of

capacity of the satellite's chemical battery, although this was fully anticipated. The second satellite in this series, TUBSAT-B with a mass of 40 kg was launched on 25 January 1994 by a Russian Tsiklon launcher together with the Meteor-3-7 satellite. It is equipped with special small reaction wheels and augmented CCD-star sensors. The main purpose of the second satellite was to demonstrate that a control system consisting of three reaction wheels and a multipurpose CCD sensor can damp the residual rotation to zero, identify current orientation of the platform and re-direct the orientation to the desired target by real time interaction from the ground. The main experiment was successfully performed a few days after the satellite was launched, proving that it was possible to stabilize the spacecraft with arc minute accuracy at preselected targets. Contact with TUBSAT-B was lost on 5 March 1994 after 39 days of successful operation, probably due to a failure of the telemetry transmitter.

76. Based on the orbital experience of TUBSAT-A and TUBSAT-B, instrumentation of the third spacecraft will also include three fibre optic laser gyros. A preliminary structure of TUBSAT-C has already been manufactured and is used for three-axis air bearing experiments. The final structure will be designed and manufactured once the launch contract is signed, probably with NASA which offers free launch opportunities to universities on its Delta launchers.

77. Some initial experiments with the Earth Imaging System (EIS) instrument package have been conducted on the UOSAT series of microsatellites. An advanced set of EIS equipment is on the POSAT- 1 satellite launched in September 1993 (with a mass of about 50 kg). This system includes two identical CCD sensors which are fitted with different lenses, offering simultaneous wide and narrow angle coverage of the Earth. Each CCD sensor has 568 x 560 active pixels, electronic exposure control and 256 grey scales. The wide-angle camera has a field of view of 1500 x 1050 km and a mean ground resolution of 2 km (typical for weather imaging). The narrow-angle camera with a field of 150 x 100 km and 200 m per pixel resolution is capable of capturing a range of natural and man made terrestrial features such as bridges, fields, large roads, city blocks, etc. The wide-angle camera senses in the near-IR band (810-890 nm) to give good contrast between land, sea, clouds and ice or snow. To aid its ability to resolve objects in the medium range, the narrow-angle camera uses a red filter (610-690 nm) which highlights variations in soil cover, vegetation density, and human structures. The POSAT-1 remote sensing mission is operational on a daily basis and has gathered some 6,000 images (at the beginning of 1995) with a nominal resolution of 200 m but has demonstrated the capability of detecting land features down to 20 m. It also has image processing and data compression systems that have been operational since December 1994. In the near future, increasingly sophisticated image compression software should be implemented to further improve the output.

78. While the POSAT's EIS does not claim to rival images from large and far more expensive platforms such as SPOT or LANDSAT, the detail in the narrow-angle camera data is reasonably high, unarguably demonstrating the future role for inexpensive remote sensing microsatellites. Currently, the imagery does not meet all the needs and expectations of the remote sensing community. The next step will be to develop a three-to-four band multispectral imager using high density CCD sensors (1000 x 1000 or 2000 x 2000 pixels). This type of camera, with a resolution of 80-100 m, could produce imagery similar in many ways to that produced by the LANDSAT Multi-Spectral Scanner, but at a tiny fraction of the cost.

D. The use of small satellites for disaster monitoring and mitigation

79. Development and emplacement of forest fire and other wildland fire warning systems on a global scale is important because of the severe environmental, economic, and social consequences of vegetation fires. Every year, 100,000 km^2 of boreal forest, 400,000 km^2 of tropical rain forest and 50,000-100,000 km^2 of savanna are affected by fire. Up to now, fire detection in near real-time has only been accomplished by aircraft systems on a regional scale in France and in the United States. Airborne systems have the advantage of good geometric resolution, cloud cover independence, and a close connection to the fire managers, but the drawback is that they are only capable of covering a small area. For large area fire research (including fire statistics) and monitoring, satellite systems are necessary. Current satellite sensors used for fire research (not

in real-time, but long after the occurrence of fire) are mainly the AVHRR on NOAA and the LANDSAT-TM sensor.

80. The pre-operational Fire Reconnaissance System (FIRES), recently studied in Germany, will demonstrate the feasibility and usefulness of a future operational small satellite system for fire reconnaissance. It is not only anticipated to be of use for pure detection of a fire event in large areas, but also for its ability to locate, assess the extent (in space and time) and type of the fire and provide this information to local authorities on a timely basis. In addition to this primary task, the system should be able to solve secondary problems such as the assessment of vegetation damage, assessment of atmospheric pollution, and the evaluation of the revitalization of burned areas. Furthermore, when the satellite is not over vegetated areas, its sensor system can contribute to other remote sensing tasks related to high temperature detection.

81. The Smart Multi-Sensor System will be optimized to meet the primary objectives of FIRES. In order to provide the necessary fire information within a few minutes, the sensor system must have a substantial capability for on board decision making and autonomous control. The satellite bus will have a mass of 500 kg, including less than 100 kg of instruments and will be injected into a heliosynchronous orbit with an inclination of 99 degrees, at an altitude of 888 km and with an orbital repeat time of one day (14 revolutions per day). The planned launch date is 1998.

82. Another example of the innovative use of small satellite technology is the Small Technology Initiative of NASA. The first two satellites, named Lewis and Clark, will carry more than 30 different technology demonstrations. Lewis will fly three instruments, including a "hyper-spectral imager" having 384 spectral bands (the operational LANDSAT satellite only has seven bands). It is designed to enhance traditional remote sensing applications in agriculture, global environmental monitoring, forestry, land management and industrial planning. Clark will carry four scientific payloads combining a very high 3 m resolution optical imager with stereo-imaging capabilities. This will be used for commercial remote sensing, disaster management and urban planning. The satellites will have a mass of 272 kg and 317 kg respectively, from which about 70 per cent accounts for the scientific payloads (in existing satellites, it is typically 40 per cent). The launch vehicle will most likely be the Pegasus-XL. The Integrated Product Development team, which will manage the project, consists of more than 35 members from the manufacturing company, NASA centres, universities and high schools.

E. Small satellites for national health and health services

83. The need to expand the availability of quality medical care is particularly great in developing countries, where 80 per cent of the population lives in rural areas while the majority of physicians live in the cities, most often in and around the capital. The access of rural inhabitants to adequate health care facilities is often hampered by poor roads and telecommunications. Space technology could facilitate and enhance health care through dissemination of health information to rural areas, collection of health information from rural areas, administration and coordination of the health network, and education of health care personnel.

84. A satellite health network has been proposed for West Africa by an American non-profit agency, Volunteers in Technology Assistance (VITA), using a constellation of small LEO communication satellites to link regional medical centres with village clinics and mobile health teams. Where more economical, two-way radio-telephones would be used to link villages or mobile units to local clinics, which in turn would be linked to the regional centre via satellite. It was estimated that ten microsatellites could be built and launched for about $21 million, while about $30 million would be required for the medical facilities and the earth station network. Such a system could dramatically improve the access of rural people to good medical care. If successful, this experiment will serve as a model for other remote regions.

85. The experience obtained during experiments with the Healthsat project involving the UOSAT-3 (later re-named HEALTHSAT-1), UOSAT-5 and HEALTHSAT-2 microsatellites, will be applicable to future

projects in this field. There are already functioning HEALTHSAT-2 terminals in Eritrea, Ghana and Sudan. The goal is to provide inexpensive digital communications from the United States, Canada and Europe for medical schools, hospitals and medical libraries throughout Africa.

F. The use of small satellites for education and training

86. The recent availability of relatively low cost launch opportunities has made it conceivable for educational institutions to develop, manufacture, test and operate a small satellite. There is always an emphasis on the active participation of the university community (professors, students, postgraduates) which gives them invaluable practical experience with space technology and scientific research.

87. For example, the first Spanish microsatellite, UPM/SAT 1, with a mass of 47 kg, has been designed and manufactured by the Universidad Politécnica de Madrid (UPM). The purpose was to produce a low cost platform with a moderately long operational life capable of future evolution. It was successfully launched on 7 July 1995 as an auxiliary payload of the Ariane-40 rocket carrying the French Helios-1A satellite. The main experiment on the satellite comprises monitoring of the behaviour of a fluid configuration called liquid bridge in microgravity conditions. Developing a moderately complex design in a university environment should allow professors and students to get the experience necessary for future, more complex projects.

88. The Sunset satellite being developed by graduate electronic engineering students at Stellenbosch University in South Africa is planned for launch in early 1996. It is a 50 kg Ariane launcher compatible microsatellite capable of three colour stereo imaging of the Earth. Pictures can be transmitted in real-time or stored on the satellite. The attitude of the satellite can be controlled within 1 milliradian. The communications package includes an S-band downlink, and amateur radio store and forward communications with an audio repeater to stimulate radio interest among school children. Coarse attitude stabilization is provided by gravity gradient and magnetic torque is improved by small reaction wheels during imaging. Continuous altitude sensing is by magnetometers, solar sensors, visible horizon sensors and a star sensor.

89. The Sunset satellite engineering related research by graduate students and academic staff is the most important element of the programme. The total development time for the first microsatellite is expected to be four years, which includes establishing the research unit and design competence in the student group. The development of the first South African microsatellite is being funded by donations from private companies and matching funds from the Foundation for Research Development. The motivation is for the support of research promotion, technology development and the training of technical manpower.

90. The laboratory of Space Technology at the Helsinki University of Technology was founded in 1988 due to an increased need for education in space technology, as Finland had recently become and associate member of ESA. The main area of interest in the laboratory is microwave remote sensing. The first Finnish satellite programme, the Helsinki University of Technology Satellite (HUTSAT) was begun in 1992. The 50 kg HUTSAT is designed for launch as an auxiliary payload of the Ariane (probably around 1998). The scientific mission of HUTSAT is the three-dimensional mapping of charged particle drifts in several spectral regions. The primary goal of the project is to teach satellite technology to undergraduate and postgraduate space technology students. Over 50 students have participated during the first two years of the project. Some of them carried out only short assignments, but many others accomplished a significant amount of work participating at a postgraduate seminar or a special course on small satellite technology. The feasibility study for the HUTSAT project was conducted solely by students during a postgraduate seminar. It was discovered that if the students are given a certain amount of freedom to solve given problems, the results are sometimes extremely innovative and surprising.

91. Similarly, the concept of the Teaching Company Scheme Satellite (TUCSAT) has been developed under a joint project run by Satellites International Limited, Newbury, and the University of Southampton, United Kingdom. It is aimed at promoting closer links between industry and academia. In evaluating the

measurements which can be made from a small satellite it is important to take account of both the requirements of the Earth observation community for specific data collection as well as the feasibility of making the required measurements within the limits of mass, power and control available on a sub-400 kg satellite. It was therefore decided to define a payload envelope for TUCSAT capable of supporting a number of different systems, rather than to optimize the satellite for a single system and design the configuration and structure around that instrument. This allows two options for the implementation of a TUCSAT-based mission.

92. First, a particular instrument could be identified in association with the producer of the instrument, which could include academic, scientific or commercial establishments, and then the entire system could be offered to a potential customer as a sole use or shared source of data from that instrument, for example in the detection of pollution, or for land use monitoring. The second option is that the satellite bus could be offered to an instrument producer as a low cost flight opportunity, either using the baseline TUCSAT bus or a slightly modified version. A preliminary study has shown that TUCSAT could provide a platform for a range of remote sensing instruments up to 80 kg, with a payload volume of 0.3 m^3. The satellite will support payload operations with an advanced on board data handling system, and a three-axis attitude determination and control system.

VII. POSSIBILITIES OF GREATER INTERNATIONAL COOPERATION IN THE FIELD OF SMALL SATELLITES

93. The opportunities for small and medium size countries to enter into space activities at a relevant level have, in the past, been very limited. Over the past decade, however, technological advances in materials and microelectronics, together with experience gained previously, has allowed many significant space missions to be performed with small satellites. In recognition of the importance of this trend for international cooperation in outer space, the International Academy of Astronautics (IAA) at its meeting in August 1992, elevated the status of its subcommittee on small satellite programmes to the status of a full committee. At the same time, a new subcommittee on small satellites for developing nations was created under the auspices of this committee.

94. According to its terms of reference, the subcommittee on small satellites for developing countries will assess the benefits of small satellites for developing nations in the field of education, space science, communications, Earth observation, medical care etc. It will assess how and to what extent small satellites may contribute to the sustainable development of those nations by providing access to advanced technology and management techniques and by fostering international cooperation. The subcommittee is also concerned with the identification of mechanisms for technical as well as for financial support. It will also develop awareness on those matters in both industrialized and developing nations. The subcommittee will prepare and disseminate the relevant information by organizing workshops and by publishing its findings. It will liaise with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the International Space University (ISU) as well as with the International Astronautical Federation (IAF), particularly with its Committee for Liaison with International Organizations and Developing Nations (CLIODN).

95. The long term goals of the subcommittee are to promote the use of small satellites for the benefit of developing countries. An assessment of these benefits is made on a regional basis, starting with the situation in Latin America. Each assessment is to be prepared during a workshop organized by the subcommittee with representatives of interested countries. The resulting reports will be published and serve as a basis for further actions. The first regional workshop was held on 20 to 23 June 1994 in São Jose dos Campos, Brazil, by invitation from INPE. Some of the conclusions and recommendations from the workshop are provided here because they contain ideas that are also applicable to other regions.

96. From the previous studies prepared by the IAA on the subject of small satellites, and from the results of this workshop, it was concluded that small satellite systems offer the following benefits:

- An independent national space programme can be developed within a short period of time and at relatively low cost, thereby allowing quick entry into the space sector. The study and development of space instrumentation, spacecraft components, sounding rocket programmes, individual small satellite programmes, and cooperative small satellite programmes are low cost opportunities to commence space activities.

- Fairly sophisticated scientific and technological experiments can be flown in space at modest costs, including space physics, astronomy, technology demonstrations, communications experiments, and acquisition of Earth resource data, including disaster information.

- Small satellites present an opportunity for training engineers and engineering students in all engineering disciplines, including software development for on board and ground computers, and in the management of sophisticated technical programmes.

- Opportunities are available for national and international cooperation, to acquire advanced technologies and upgrade a nation's technical expertise in new areas.

- Small LEO satellites offer the promise of inexpensive telecommunications services, and opportunities for international cooperation. Such services could include mobile communications for ships, aircraft, land transportation and personal communications.

- Small satellite systems provide the opportunity to invest limited resources to gradually increase a nation's space infrastructure.

97. Beyond those general benefits, the workshop noted some specific benefits and expected returns from the utilization of small satellites in Latin America:

- Improvement of agricultural and animal productivity in medium to large size rural properties due to better weather forecasting, identification of soil characteristics, improvements in communications and transportation.

- Lowering of transportation costs, made possible through the optimization of truck, bus and ship routing and location, with favourable impacts on prices of goods.

- Provision of communications for the basic needs of small rural settlements in remote areas.

- Expansion of availability, and thus lower prices, for better technology for everyday electric and electronic goods and materials, an indirect effect of the industry participation on quality demanding space projects.

- Improvements in natural disaster detection and relief, made possible by systems that integrate scientific, communications and remote sensing satellite networks.

- Educational programmes for populations in remote areas.

- Job creation in the space and ground facilities industries.

98. Finally, in view of the general benefits, and of the expected return to societies, and taking into account some of the difficulties already experienced, the following recommendations are made. Although they were specifically targeted at countries in Latin America, they nevertheless are valid for other regions of the world.

- Governments should take the steps necessary to make the public and the policy-making governmental officials aware of the importance and benefits of a national space programme so that funding for space activities will be included in the national budget on a sustained basis.

- Countries that are, or want to be, involved in a space programme should develop and publish its national policy so that areas of cooperation can be identified.

- Industry should take initiatives and play a more active role in investing in the development of increased national space activity.

- Any sensitive technologies involved in technology transfer should be identified in advance by the countries involved and related barriers overcome.

- Countries should identify and propose mechanisms to improve access to available technologies for scientific applications.

- Regional representatives should participate in seminars, professional society meetings and other similar fora for the exchange of the latest technical data.

- Countries should attempt to find a market for existing national expertise to sell space hardware and software to other countries for their space programmes, using national academic and industrial facilities.

- In order to improve the access to space of developing countries, particularly through easy access and availability of piggyback missions, the international launch community should periodically publish and distribute notice of potential low cost launch opportunities.

VIII. CONCLUSIONS

99. The eventual success of small and micro-satellites is not considered to be in doubt, but before the full potential of these emerging technologies can be realized it will be necessary to radically re-think the way missions are specified, realized, funded and operated. The changing role of international cooperation to this effect should be further explored. Because of the diverse nature of both applications and instruments, their needs are unlikely to be met with a common small satellite bus design, but more intensive exchange of experience with different designs could eventually lead to some kind of standardization. The ability to adapt existing hardware readily and cheaply will also be a valuable economic asset for both manufacturer and user.

100. Among the main difficulties in promoting the use of small satellite technology for developing countries is the fact that the countries with established space programmes frequently do not understand the scope of problems within the developing countries and that there is a lack of adequately trained local personnel. In this context, it would be extremely valuable, if the United Nations Committee on the Peaceful Uses of Outer Space pay more attention to this issue. It is therefore pertinent, that the theme fixed for special attention during the thirty-third session of the Scientific and Technical Subcommittee in February 1996 is "Utilization of micro- and small satellites for the expansion of low cost activities, taking into account the special needs of developing countries".

101. Based on the results of its deliberations about this special theme, as well as on recommendations contained in the present report, the Committee might propose some ways and means of assuring substantial

progress in international cooperation in this rapidly developing field. It might for example recommend, that one or more of the educational activities of the United Nations Programme on Space Applications be devoted to the theme of micro- and small satellites.

List of acronyms

ASAP - Ariane Structure for Auxiliary Payloads
ASI - Italian Space Agency
AVHRR - Advanced Very-High Resolution Radiometer
CAD - Computer Aided Design
CAM - Computer Aided Modelling
CCD - Charged Coupled Device
CDMA - Code Division Multiple Access
CEI - Central European Initiative
CESAR - Central European Satellite for Advanced Research
CLIODN - Committee for Liaison with International Organizations and Developing Nations (of IAA)
CONAE-Comision Nacional de Actividades Espaciales (Argentina)
COSPAR - Committee on Space Research
EIS - Earth Imaging System
DCP - Data Collection Platform
DUOS - Domestic Urban area Observation Satellite
GAS - Get Away Special
GSO - Geostationary Orbit
GTO - Geostationary Transfer Orbit
GSE - Ground Support Equipment
HEO - Highly Elliptical Orbit
HUTSAT - Helsinki University of Technology SATellite
IAA - International Academy of Astronautics
IAF - International Astronautical Federation
INPE - National Institute for Space Research (Brazil)
INTA - National Institute for Aerospace Technology of Spain
ISAS - Institute for Space and Astronautical Sciences of Japan
ISRO - Indian Space Research Organization
JUNO - Joint Ultra Violet Night Sky Observer
LANDSAT-TM - Land (Remote Sensing) Satellite Thematic Mapper
LEO - Low Earth Orbit
MAGION - Magnetosphere and Ionosphere (Czech Subsatellite)
MCC - Mission Control Centre
MIT - Magnetosphere-Ionosphere-Thermosphere Earth Environment
MSTMC - Multipurpose Space Transport Missile Complex (in Russia)
NASDA - National Space Development Agency of Japan
OICETS - Optical Intersatellite Communications Engineering Test Satellite
OSC - Orbital Sciences
PLM - payload module
POSAT - Portuguese Satellite
RS - Rohini Satellite Series
RTS - Remote Tracking System
SAR - Synthetic Aperture Radar
SPARTAN - Shuttle Pointed Autonomous Research Tool for Astronomy
SPELDA - Structure Porteuse Externe pour Lancement Double Ariane
SROSS - Stretched Rohini Scientific Satellite
START - Strategic Arms Reduction Treaty
SCD - Satellite de Coleta de Dados (Brazil)
SSTL - Surrey Satellite Technology Ltd.
TDMA/SCPC - Time-Division Multiple Access/Single-Channel-Per-Carrier
TEMISAT - Telespazio Micro Satellite

TIR - Thermal Infrared Radiometer
TT&C - Telemetry, Tracking and Command
TUBSAT - Technical University of Berlin Satellite
TUCSAT - Teaching Company Scheme Satellite
UHF Ultra High Frequency
UOSAT - University of Surrey Satellite
VNIR - Visible and Near Infrared Radiometer

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COMMITTEE ON THE PEACEFUL
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REPORT ON THE UNITED NATIONS/INTERNATIONAL ASTRONAUTICAL FEDERATION WORKSHOP ON SPACE TECHNOLOGY FOR HEALTH CARE AND ENVIRONMENTAL MONITORING IN THE DEVELOPING WORLD, CO-SPONSORED BY THE EUROPEAN SPACE AGENCY, THE COMMISSION OF THE EUROPEAN COMMUNITIES AND THE GOVERNMENT OF NORWAY AND HOSTED BY THE NORWEGIAN SPACE CENTRE

(Oslo, 28 September-1 October 1995)

CONTENTS

		Paragraphs	*Page*
INTRODUCTION		1-8	2
	A. Background and objectives	1-5	2
	B. Participants	6-8	2
I.	PRESENTATIONS AND DISCUSSIONS DURING THE WORKSHOP	9-42	3
	A. General themes	9-14	3
	B. Telehealth	15-26	3
	C. Environmental monitoring and disaster management	27-42	5
II.	OBSERVATIONS AND RECOMMENDATIONS	43-70	7
	A. General themes	43-55	7
	B. Telehealth	56-61	8
	C. Environmental monitoring and disaster management	62-70	9
Annex.	Programme of the Workshop		11

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INTRODUCTION

A. Background and objectives

1. The General Assembly, in its resolution 37/90 of 10 December 1982, endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and an autonomous technological base in space technology for developing countries. At its thirty-eighth session, in June 1994, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications for 1995, as recommended by the Scientific and Technical Subcommittee at its thirty-first session. Subsequently, the General Assembly, in resolution 49/34 of 9 December 1994, endorsed the activities of the Programme on Space Applications for 1995.

2. The present report contains a summary of the proceedings of the United Nations/International Astronautical Federation Workshop on Space Technology for Health Care and Environmental Monitoring in the Developing World. Organized as part of the 1995 activities of the Office for Outer Space Affairs of the United Nations and its Programme on Space Applications, the Workshop was the fifth in a series conducted by the United Nations, and was held in conjunction with the 46th Congress of the International Astronautical Federation (IAF) at Oslo, Norway. Previous symposia and workshops in the series have been held in Austria, Canada, Israel and the United States of America.

3. The main objective of the Workshop was to provide participants with information on the possibilities offered by current space technologies and to discuss ways in which they could be used in ongoing or planned programmes and projects of the participants.

4. During the course of the Workshop successful models of space applications were presented. Through panel discussions, the Workshop developed general principles on how developing countries could use space technologies, including remote sensing and space communications systems for health care, environmental monitoring and economic and social development.

5. The present report covering the background, objectives and organization of the Workshop, as well as the observations and recommendations made by the participants, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants will report to the appropriate authorities in their own countries.

B. Participants

6. The United Nations invited developing countries to participate in the Workshop. Participants were required to have university degrees in engineering, physics, biological or medical sciences or other fields related to the themes of the Workshop. The participants were working in programmes, projects or enterprises in which space technology could be utilized. A few policy makers, at a decision-making level, from both national and international entities were also invited.

7. Funds allocated by the United Nations, IAF and the other co-sponsors for the Workshop were used to cover international air travel and per diem expenses for the period of the Workshop and the IAF Congress for selected participants from developing countries.

8. The following Member States and international organizations were represented at the Workshop: Bangladesh, Brazil, Cambodia, China, Costa Rica, Cuba, Egypt, Ethiopia, Ghana, India, Indonesia, Iran (Islamic Republic of), Jordan, Mauritania, Mauritius, Nicaragua, Nigeria, Peru, Philippines, Senegal, Sierra

Leone, Sri Lanka, Syrian Arab Republic, Thailand, Togo, Uganda and Viet Nam; Office for Outer Space Affairs of the United Nations and World Health Organization (WHO); and Commission of the European Communities, European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), European Space Agency, European Telecommunications Satellite Organization (EUTELSAT), International Astronautical Federation, International Mobile Satellite Organization (Inmarsat), International Space University (ISU) and International Telecommunications Satellite Organization (INTELSAT). Speakers, chairmen and participants from Austria, Canada, France, Germany, Italy, Malta, Netherlands, Norway, United Kingdom of Great Britain and Northern Ireland and the United States of America also took part in the Workshop.

I. PRESENTATIONS AND DISCUSSIONS DURING THE WORKSHOP

A. General themes

9. The Workshop featured a series of presentations on relevant space application fields by experts from both developed and developing countries. A representative from each of the developing countries presented outlines of its national programme. Three panel discussions preceded open discussion sessions where the participants interacted, providing information, comments, questions, recommendations and suggestions.

10. It was stressed repeatedly during the meeting that the problem with adopting space technology in developing countries was not with the technology itself, which existed and was readily available. The problems were regulatory, legal, political, institutional, financial and educational. It was suggested that a future UN/IAF workshop might focus on that matter and make recommendations to reduce those problems.

11. The value of space technology to developing countries was clearly recognized by the participants, as was the necessity for stronger regional cooperation and collaboration. It was also recognized that there was a strong need for more extensive education in the benefits of space technology at all levels, from school children to political leaders. In particular, school children should be taught subjects related to space science and technology which were most likely to be relevant to the country in future.

12. Space technology had become an increasingly vital part of everyday life, characterized by growing costs and complexity, which meant that most developing countries must be extremely selective about the scope and pace of their own space activities. It had been realized that space technology could be a valuable tool for enhancing international security.

13. For example, a proposal for the use of a constellation of geosynchronous equatorial and polar orbiting satellites, the Global Satellite Network for Education, Tele-health and Disaster Management (GLOSNETAD), was outlined. GLOSNETAD would be connected by a network of ground stations as a global arrangement for education, health care and disaster management,

14. The ever-increasing cost of space technologies and participation in space activities made international cooperation absolutely necessary for many countries wishing to benefit from the technology. The need for international cooperation was therefore repeatedly stressed.

B. Telehealth

15. Space technology provided entirely new dimensions to the way in which health care and education could be delivered. Conventional approaches required a face-to-face relation between the patient and the health-care provider. That generally meant that patients in remote areas had very limited access to high-quality,

specialized medical care. The telephone and two-way radio had improved the situation by permitting audio communication between health-care persons in a remote area and specialists at a major centre. However, the equitable availability of high-quality medical care depended upon interactive audio-visual communication that could be provided by space communications technology.

16. Telehealth was the practice of health care using interactive audio, visual and data communication. It included health-care delivery, diagnosis, consultation, treatment, communication of data and education of both the doctor and the patient. Recent advances in technology, especially in video storage, processing, retrieval and transmission had helped to bring telehealth within the reach of a much broader community.

17. Telehealth was based on the fundamental premise that there should be equitable access to quality health care. The cost of health care was rising everywhere. As a function of a country's gross national product (GNP), the cost had shown a steady rise over the years. Expectations of health care also continued to rise. However, available resources were declining. Telehealth could slow the rate of cost increases. Moreover, it could help to achieve the goal of equitable access.

18. In about 50 projects that had been followed by WHO, it was found that there were significant savings in travel costs of physicians and patients. Telehealth had been successfully used for pathology, radiology, magnetic resonance imaging, cardiology and further medical consultations.

19. In China, the direct and active participation of medical universities in the use and promotion of space technology had been critical in public health education and medical instruction in remote areas. Interactive satellite transmission technology was one of the best and most reliable means of conveying health knowledge to medical workers in rural areas. Since 1993, the West China University of Medical Sciences had actively participated in developing radio and television programmes providing rural areas with basic information not only on health-care services, but also on epidemic diseases, thereby allowing timely mitigation strategies.

20. Financial and technological support from developed countries was one of the most important factors in successfully promoting the sharing of benefits of space technology to humankind. Developing countries should place a higher priority on the active participation in and application of space technology in the fields of health care and education. They should also improve their health care and educational organizations and infrastructures.

21. The HealthNet programme was developed in 1989 to cooperatively share information and communications services to support public health and medical research in the developing world. HealthNet was currently in operation in 15 African and 5 Asian countries.

22. The original intent was to use low Earth orbit (LEO) satellites to reach rural and remote areas. Five ground stations with a computer, radio and antenna had been established. The satellites were low cost and could be used for electronic mail, with delivery anywhere in the world within 12 hours.

23. In an effort to address the problem of the globally unbalanced provision of medical and educational services, participants in the ISU 1994 summer session programme at Barcelona developed a proposal to establish the Global Access to Tele-health and Education System (GATES). By using advanced communications and information technologies for telehealth and tele-education applications, GATES would improve basic medical care and education on a global scale.

24. The goal of the GATES project was to reduce inequalities in health and education within countries and between countries by using telecommunications technology. The unique aspects of the GATES system were that it took a global approach and it had the dual objective of combining health care and education. The dual

approach was justified by the fact that the highest medical and educational needs generally appeared in the same areas. Furthermore, the basic communications requirements for health care and educational services were very similar.

25. Students working on that project were especially concerned with minimizing costs and keeping the infrastructure as simple as possible. They recognized that the largest problems were economic and political. An efficient management structure was proposed. Membership would be open to any country, but services would be available to anyone, regardless of membership. GATES would not only be used for health and education services, but also for environmental and disaster management applications.

26. The United Nations and other international organizations could influence policies that would result in the development of telehealth, distance education systems and further networks where they were needed. Current and future satellite systems could do much to rectify the gross knowledge imbalance that existed in many parts of the world. Regulatory, legal and political issues must be addressed and resolved if support services for health care and education were to be met. Those issues should not be permitted to inhibit the development of essential worldwide satellite services that were feasible.

C. Environmental monitoring and disaster management

27. Presentations on remote sensing focused on the opportunities for using satellite data for environmental monitoring. It was stated that developing countries would be able to utilize new developments in remote sensing systems to gain access to significantly greater quantities of valuable data. Presentations highlighted applications in areas such as forestry, geology and mineral resources, cartography and other fields. It was emphasized that compared with conventional ground surveys, satellite observations provided less detail but much greater economy, particularly when continuous and repetitive monitoring was required.

28. Although the European Remote Sensing (ERS) satellite system of ESA was not specifically planned to meet the needs of developing countries, its data played a vital role, in particular in the fields of environmental monitoring, food production and climate change. In that context it was emphasized that national aid agencies should substantially increase the use of satellite data in projects funded by them. They required, however, greater awareness of the potential of space technology for sustainable development.

29. Aid for food production and preservation of the environment was important not only for humanitarian reasons, but also because it benefits all the donors by cost savings and improved effectiveness in managing emergencies; it also contributed to world political stability. Space agencies benefited from involvement in aid projects in fields such as education by generating increased public and political interest and by demonstrating their usefulness in converting general policy statements into technical implementation.

30. The Workshop identified several areas where cooperation could be improved, such as an assessment of user requirements of the developing countries, accessibility of satellite data and information services at reasonable cost, promotion of well-designed pilot projects to assure transition to ongoing operational status, increased on-site education and training, provision of infrastructures for satellite data acquisition and better use of existing user interfaces. It was agreed that the Committee on Earth Observation Satellites (CEOS) would be the appropriate forum in which to discuss those issues.

31. MERCURE, a satellite-based communications capability donated to the United Nations Environment Programme (UNEP) by member States of ESA, was discussed during the Workshop. Six European countries had provided the space segment and 16 antennas with related hardware and software. It would provide UNEP with two different networks: subnet A, the backbone, using 7.3 m antennas providing 384 kilobytes per second (kb/s); and subnet B, for remote areas using 2.4 m antennas providing 64 kb/s.

32. UNEP currently transmitted about 6 million pages of data to approximately 3,000 users. Telecommunications costs had quadrupled over the past few years to the current level of US$ 4 million annually. The service based on MERCURE would be much more effective, and the cost to UNEP would be only US$ 6 million over a period of four years. The backbone system would be based on 64 channels, each of which would have a capacity of 384 kb/s. Two INTELSAT satellites - one over the Atlantic Ocean and the other over the Indian Ocean - would be used.

33. The MERCURE system would also provide much wider access to the Internet in Africa, and facilitate much more efficient dissemination of documents, environmental data, images and messages, resulting in substantial savings in telecommunications costs.

34. The Tropical Ecosystem Environment Observation by Satellite (TREES) project was sponsored by the Joint Research Centre of the Commission of the European Communities and ESA. Its main objectives were the development of techniques for a global tropical forest inventory using data from the advanced very high resolution radiometer (AVHRR) of the United States of America as well as from the ERS-1 satellite; the development of techniques for the detection and monitoring of active deforestation areas and measuring deforestation rates in critical areas; and the development of a comprehensive Tropical Forest Information System to support the modelling of tropical deforestation dynamics.

35. The baseline assessment of tropical forest cover using AVHRR had been completed. Synthetic aperture radar (SAR) data over 18 selected areas had been examined with a view to investigating the feasibility of vegetation mapping with ERS-1. In the future, research methodologies would be tested for monitoring deforestation, and other data sources, such as SPOT and ATSR-2, would be examined.

36. In 1992, the Panamazonia Project was proposed with the objective of developing a system for monitoring the tropical forest in Latin America using satellite remote sensing. An experienced technical team was selected from agencies in Bolivia, Brazil, Chile, Colombia, Ecuador, French Guyana, Peru and Venezuela. Visible, near-infrared and short-wave infrared images had shown significant environmental damage as a result of deforestation. It was anticipated that, in the near future, the Panamazonia Project would also provide data on the exploitation of mineral resources.

37. Considering the magnitude of the losses caused by natural disasters and recognizing the need for a global initiative, the United Nations proclaimed, by resolution 44/236 of 22 December 1989, the 1990s the International Decade for Natural Disaster Reduction

38. Whereas natural disasters included floods, earthquakes, hurricanes, landslides and certain types of widely spreading infectious diseases, human-induced disasters included explosions, armed conflicts, motor and aircraft accidents, chemical spills etc. Forest fires could be of either category.

39. Space technology offered tremendous potential for assisting in disaster response and mitigation. Telecommunications satellites addressed issues related to mass awareness, warning, education and training, as well as emergency communication in the event of a disaster. Remote sensing satellites were useful in formulating disaster mitigation measures and in monitoring, and could assist in risk analyses by promoting understanding of the processes that led to natural disasters.

40. A national risk assessment system was evolving in India to minimize the harmful effects of hazardous events. That was a national mission, integrating space applications along with other relevant information for disaster warning, disaster mitigation and efficient management of hazardous events. Unfortunately, only a few countries had the means to operationally utilize space technology for hazard management. Increasing

access to space technology for such uses could be promoted through appropriate international coordination and cooperation.

41. Fire was the most common natural cause of forest destruction in Canada. Several projects were in progress to monitor the extent of such damage. The most advanced forest management information systems were those currently being used to enhance the effectiveness of fire-suppression activities. Many of those systems made use of satellite remote-sensing data to categorize the fuel type, which was an important factor in determining the risk that a fire would spread. Combining the fuel type with other parameters enabled fire-suppression authorities to combat forest fires more effectively, thereby dramatically reducing annual losses and achieving significant savings in fire-suppression costs.

42. Several projects using remote sensing in North America were related to monitoring forest damage caused by forest fires and insect infestations. Decision support systems were being developed to provide risk assessment and management planning to minimize losses caused by insects. In many such projects, remote sensing was used as a tool to acquire information related to damage caused by insects. Geographic Information Systems (GIS) were used to perform spatial analyses and to produce risk maps in all of those projects.

II. OBSERVATIONS AND RECOMMENDATIONS

A. General themes

43. The importance of merging space technology with other conventional techniques was stressed throughout the Workshop. The space sector should therefore not be considered in isolation. Space technology in developing countries should be related to use by the public sector, namely for telecommunications, remote sensing, meteorology and navigation.

44. Space science should continue to play a vital role, as even a modest investment in that area could pay big dividends. Space science was well recognized as a valuable contributor to the advancement of technology, particularly in the area of data processing. Competence in space science contributed to competence in areas far beyond the specific field of research undertaken.

45. It was agreed that the Workshop would help to increase awareness of the status and possibilities of applications of space technology in developing countries. However, one impediment to the introduction of space technology in developing countries was the lack of awareness and understanding on the part of political leaders and senior officials, which often resulted in a lack of political will. To overcome that difficulty, it would be helpful to select a few good people who had been involved in successful programmes as "ambassadors" to developing countries. Their credibility would probably have a great impact.

46. It was important to balance space technology with the capabilities and resources of developing countries. Many aid projects provided expensive technology to developing countries that could not sustain such systems after the initial project was concluded. Fundamentally, every country must have its own policy to initiate and integrate space projects into its national programmes.

47. It was recommended that a step-by-step approach be taken to the introduction of space technology. Although there was already a large market in developing countries for space technology products, and opportunities existed for joint ventures, more consideration should be given to building up the infrastructure required to successfully implement space programmes.

48. The importance of having staff that were not only trained, but competent and confident in dealing with all aspects of the applications of space technology, was stressed. Technological advances must be accompanied by similar progress in the level of understanding of users. However, while national space coordinating bodies were needed at senior levels to set policy, not every country needed a space agency.

49. In order to facilitate the implementation of space programmes, international cooperation between developed and developing countries, as well as among developing countries themselves, still needed to be improved. It was repeatedly recommended that the practical use of satellite data with emphasis being placed on developing simple-to-use and low-cost applications should be promoted in developing countries.

50. Better access to Internet services should be available for developing countries. Information on health, remote sensing and GIS was especially useful, and every institution interested in such information should have access to it.

51. There was a need for better standards and a more liberal approach to pricing in the area of commercial telecommunications. In that context, international organizations such as the International Telecommunication Union, but also the operators of local platform transmitter terminals (PTTs), should be encouraged to be more liberal in their pricing structures.

52. To achieve a national commitment to provide resources to space technology, a clear cost-benefit analysis for each project should be prepared for decision makers. Decision makers in developing countries must be convinced that a judicious expenditure of limited resources on space programmes would substantially contribute to social stability and economic growth.

53. The need was stressed for participants to pass on their experience to their colleagues, and in particular to decision makers in their home countries. Furthermore, participants should inform their local PTTs and industries of the discussions and results of the Workshop.

54. One of the future UN/IAF Workshops should focus on the means of overcoming the regulatory, legal, political, financial and educational obstacles to the better exploitation of space technology in developing countries.

55. The involvement of the private sector in such meetings should be increased. In particular, the participation of PTTs and medium-sized companies (of 20 to 100 employees), which could provide relatively low-cost technology and services to developing countries, should be encouraged.

B. Telehealth

56. The potential of space technology for improving traditional public health-care services was recognized by participants. Space technology had a vital role to play in enhancing medical services, medical consultations and the monitoring of epidemic disease, particularly in remote and rural areas.

57. Recent improvements in satellite communications technology and information systems had resulted in a dramatic increase in telehealth programmes and projects worldwide. Linking remote locations to an urban medical centre provided an opportunity for specialist consultations that might not be possible otherwise. Thus, telehealth systems could reduce critical delays in the delivery of health care by providing and expanding access to remote areas.

58. Whereas some telehealth applications required real-time capability (video conferences for telesurgery, telepsychiatry etc.), other applications, such as image and file transfer, consultations or research, could be

supported in a store-and-forward mode. In the future, telehealth using mobile satellite communications systems such as Inmarsat could form an integral part of national or regional emergency planning.

59. Developing countries should give higher priority to active participation in, and the application of, space technology in the fields of health care and education. They should also improve their health care and educational organizations and infrastructures.

60. The direct and active participation of medical universities in the use and promotion of space technology was critical in public health education and remote medical instruction.

61. The United Nations and other international organizations could influence policies leading to the development of telehealth and distance education systems where needed. Current and future satellite systems could do much to rectify the knowledge imbalance that existed in many parts of the world. However, not only technical, but also regulatory, legal and political issues must be addressed and resolved if support services for health care and education were to be developed. Those issues should not be allowed to inhibit the development of adequate, worldwide satellite services that were already feasible.

C. Environmental monitoring and disaster management

62. The unique capabilities of remote sensing satellites for providing comprehensive, synoptic and multi-temporal coverage of large areas at regular intervals had been and would be an indispensable tool for continuous environmental monitoring.

63. Although many developing countries had indigenous experts in space applications, it was nevertheless difficult for them to solve environmental problems on their own. Outside assistance and expert advice was therefore essential to the successful application of space technology for sustainable development.

64. A more effective coordination policy must be established in many developing countries in order to integrate satellite remote sensing into national, social and economic development programmes. There were examples of highly qualified individuals in well-equipped remote sensing laboratories who were not contributing to national plans because of the lack of communication with national policy makers and decision makers, who were thus not aware of the benefits that space applications could bring to national efforts to achieve sustainable development.

65. The pricing and independence of remote sensing data were critical for the integration of remote sensing into national programmes. Governments and agencies should therefore be encouraged to reduce prices on remote sensing data and to reduce copyright restrictions.

66. In connection with the joint TREES project of the Commission of the European Communities and ESA, a deforestation monitoring system should be developed, combining low- and high-resolution data and using the Tropical Forest Information System.

67. Only a few developing countries currently had telecommunications systems capable of coping with disasters. Furthermore, traditional telecommunications systems were often severely affected by disasters such as earthquakes, floods or hurricanes. Mobile satellite systems should therefore be used.

68. Voice, fax and data terminals should continue to be positioned at strategic locations so that an uninterruptible source of warning would be available even if the local radio or television infrastructure had been disabled by a disaster. A network of terminals would be particularly effective if it were connected to an appropriate regional or global database of GIS or of relevant disaster information.

69. In many developing countries, land mines presented a serious obstacle to social and economic development. The process of de-mining was very slow, tedious and dangerous. Thus, it was recommended that satellite remote sensing should be increasingly used in order to help affected developing countries deal with that problem in a more effective manner.

70. The continuous establishment of training centres would play a vital role in promoting and applying space technology for sustainable development. It was suggested that remote sensing and GIS training be combined into one national training centre. It was also recommended that such centres should train staff from different institutions, so as to encourage information sharing, reduce the amount of overlapping, and minimize the capital investment required.

Annex

PROGRAMME OF THE WORKSHOP

Date/Time	*Subject*	*Speaker/Country/ Organization*
Thursday, 28 September 1995		
0830-0900	Registration	
	Space technology applications: improving the quality of life	
0900-0945	Opening ceremony:	
	Opening statements Welcoming statements	United Nations, ESA, IAF, A. Mathisen, State Secretary, Royal Ministry for Foreign Affairs of Norway
0945-1015	Keynote address: the challenge of space technology - possibilities to enhance the quality of life	K. Kasturirangan (India), Chairman, ISRO
1015-1045	Contribution of previous UN/IAF workshops to current space activities in developing countries - a critical overview	J. Hess (United States of America)
1045-1100	**Break**	
	Space technology for better health services	
1100-1130	Improving human conditions through telemedicine programmes: current state and future perspectives	S. H. Mandil (WHO)
1130-1200	Use of satellites in telemedicine and health services	M. House (Canada)
1200-1230	Discussion	
1230-1400	**Lunch**	
	Space technology for a better and safer environment	
1400-1430	Use of satellite data in environmental monitoring and planning national development - the role of ERS and ENVISAT	B. Bizzari (Italy)

Date/Time	*Subject*	*Speaker/Country/ Organization*
1430-1500	MERCURE project: a system developed for global environmental data transmission	H. Onsrud (Norway)
1500-1530	Utilization of the satellite telecommunication system MERCURE in UNEP: UNEPnet, the green lane on the Internet	A. Brox (UNEP)
1530-1545	**Break**	
	Establishing the necessary policies	
1545-1615	National and regional space competence - arriving at an appropriate mix of space and non-space technology	R. Gibson (United Kingdom of Great Britain and Northern Ireland)
1615-1800	First panel discussion	
	Establishing policies and institutional links to promote the use of space technology (followed by general discussion)	

Friday, 29 September 1995

Space technology in health-care programmes

0900-0930	Global Access Tele-health and Education System (GATES Project)	L. Stojak (International Space University)
0930-1000	Healthnet: solving communications problems for health-care workers	A. S. Brown (United States)
1000-1015	**Break**	
1015-1045	Providing health care between countries by Telemedicine - a case-study	G. Hartviksen (Norway)
1045-1115	Satellite communications technology for continuing public health education and dissemination of information in rural areas	C. Yongxin (China)
1115-1230	Brief presentations by the participants on the theme of the session	
1230-1400	**Lunch**	

Date/Time	*Subject*	*Speaker/Country/ Organization*
1400-1545	Satellite systems in support of health-care services in remote areas, environmental monitoring and disaster preparedness and response	EUMETSAT, EUTELSAT Inmarsat, INTELSAT
1545-1600	**Break**	
1600-1800	Second panel discussion Perspectives for the use of space technology to enhance medical services (followed by General Discussion)	

Saturday, 30 September 1995

Space technology in environmental monitoring, telecommunications, disaster preparedness and response

0900-0930	The use of remote sensing for forest damage monitoring and management	M. Strome (Canada)
0930-1000	Visible, infrared and synthetic aperture radar data for detecting environmental changes - the Panamazonia Project	P. R. Martini (Brazil)
1000-1030	TREES: global tropical forest monitoring using remote sensing data	F. Achard (Commission of the European Communities)
1030-1045	**Break**	
1045-1230	Brief presentations by the participants on the theme of the session	
1230-1400	**Lunch**	
1400-1500	Brief presentations by the participants on the theme of the session	
1500-1530	The role of space technology in developing national assessment of risks from national hazards	M. G. Chandrasekhar (India)
1530-1600	Establishing and implementing disaster preparedness and response policies - the role of space technology	V. U. Ratnayake (Sri Lanka)
1600-1615	**Break**	

Date/Time	*Subject*	*Speaker/Country/ Organization*
1615-1800	Third panel discussion Efficient use of satellite data for environmental monitoring and management of natural disasters - a technological and political challenge (followed by general discussion)	
Sunday, 1 October 1995		
0900-1000	Presentations of chairmen of the technical sessions and general discussion to prepare report	
1000-1030	Summary of the workshop: accomplishments and review of possible follow-up actions	M. Strome (Canada)
1030-1100	Final discussion and adoption of report	
1100-1130	Closing ceremony	
1130-1200	Press conference	

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT ON THE UNITED NATIONS/EUROPEAN SPACE AGENCY TRAINING COURSE ON THE USE OF ERS-1 DATA FOR THE MAPPING AND INVENTORY OF NATURAL RESOURCES IN AFRICA

(Libreville, Gabon 15-19 May 1995)

CONTENTS

		Paragraphs	*Page*
INTRODUCTION		1-9	2
	A. Background and objectives	1-3	2
	B. Organization and programme	4-9	2
I.	SUMMARY OF PRESENTATIONS	10-25	3
	A. European remote sensing satellites and instrumentation	10-14	3
	B. Interpretation of European remote sensing satellite data for applications of national interest	15-23	4
	C. Data access and processing	24-25	5
II.	RECOMMENDATIONS OF THE WORKING GROUPS	26-29	6
III.	COURSE EVALUATION	30	7
IV.	PROPOSED FOLLOW-UP PLAN OF ACTION	31	7

Annexes

I.	Programme of the training course	9
II.	Proposed projects	11

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INTRODUCTION

A. Background and objectives

1. A mobile receiving station which is capable of receiving data from the ERS-1 and ERS-2 radar satellites has been operational at Libreville, Gabon, since late 1994. The coverage of the station is a roughly circular geographical zone centred on Libreville which extends, to the north-west, as far as eastern Mali, and to the south-west, as far as the western regions of Zambia. The territories of 23 African countries, of which 17 are francophone, are either wholly or predominantly covered by the Libreville station. The near-equatorial location of the receiving station and the cloud-penetration characteristics of radar render the station particularly useful to those countries whose exploitation of conventional optical remote sensing data has been severely hampered due to the presence of heavy cloud cover, which often obstructs observation of the ground in equatorial zones.

2. The objective of the training course was to provide participants with the knowledge and skills necessary to use radar data in a number of application areas that correspond with major regional and national interests, in particular those pertaining to agriculture, forestry, geology, mineral exploration and land use. Knowledge of radar image interpretation is becoming increasingly important because of the growing number of operational and planned radar satellites (e.g. ERS-1, ERS-2, JERS-1, Radarsat) and the attendant increasing use of spaceborne radar as a tool to monitor tropical regions. The training course was co-sponsored by the European Space Agency (ESA) and the United Nations. It was held at Libreville, Gabon, from 15 to 19 May 1995, for the benefit of francophone countries within the region served by the receiving station. The course was conducted as part of the 1995 activities of the Space Applications Programme of the Office for Outer Space Affairs, which is mandated to promote the awareness of advanced technologies and greater cooperation in space science and technology between developing and developed countries as well as among developing countries.

3. The present report includes descriptions of the organization of the training course and enumerates the recommendations for follow-up action. In particular, it details plans for a number of projects of regional interest and scope which were elaborated by the participants themselves. The report has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants are expected to report to the relevant authorities in their countries.

B. Organization and programme

4. Application forms and information on the training course were sent out in September 1994 by the United Nations to offices of the United Nations Development Programme (UNDP) for onward transmission to national authorities in 13 countries within the region: Angola, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Gabon, Mali, Niger, Togo and Zaire.

5. The training course was attended by 25 participants, 12 of whom were from Gabon. The other 13 participants were from the following nine countries: Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Gabon, Niger and Senegal. Other participants were from the Office for Outer Space Affairs, ESA, German Aerospace Research Establishment (DLR), Scot Conseil and Groupement pour le développement de la télédétection aérospatiale (GDTA).

6. Funds for the participation of the 13 international participants from developing countries were obtained from budgetary allocations of the United Nations and from financial support received from ESA. The Government of Gabon provided secretarial support and local transportation for the benefit of the participants.

7. A high official of the Ministry of Water, Forests, Post and Telecommunications, and the Environment, Mr. O. Mboulamatari, gave an address on behalf of the Government of Gabon at the opening ceremony. Addresses were also given by the representatives of ESA, UNDP and the Office for Outer Space Affairs. The Minister of Water, Forests, Post and Telecommunications, and the Environment received the representatives of ESA and the Office for Outer Space Affairs together with nine high-ranking ministry officials. This ceremony as well as those of the opening and closing of the training course were covered by the local radio, newspaper and television media.

8. The programme of the training course (see annex I) was developed by the United Nations in consultation with ESA. The course was conducted through a series of lectures and practical exercises which emphasized the use of ERS data but did not exclude discussion of other satellite radar systems. On the last day of the training course, formal presentations were made followed by discussion of regional projects prepared by the participants in working groups for which access to and the use of ERS data would be a key element. One of the highlights of the course was a visit to the Libreville ERS receiving station, which was conducted by Mr. K. Reiniger of DLR, and followed a visit to the Ariane tracking station, conducted by Mr. Audegean of the Centre national d'études spatiales (CNES), the French space agency.

9. The principal instructor of the training course was Mr. M. Fea of ESA. Supplementary technical presentations were made by the representatives of DLR, GDTA, Scot Conseil and the Office for Outer Space Affairs. A concise summary of the major topics presented during the training course is given in section I, below. This is followed, in section II, by a presentation of the recommendations of a number of working groups. In addition to informal comments communicated to the United Nations during the course, a formal course-evaluation session (see section III, below) was held on the last day of the training course to gather input which would be useful for identifying future activities which would respond best to the needs of countries in the region. The proposed plan of follow-up activities is presented in section IV, below.

I. SUMMARY OF PRESENTATIONS

A. European remote sensing satellites and instrumentation

10. There are currently two ERS satellites in operation, ERS-1 and ERS-2, launched in July 1991 and April 1995, respectively. Both satellites are equipped with microwave (radar) instrumentation which penetrates cloud cover and darkness and provides information 24 hours a day. The satellites measure many parameters which are not currently measured by existing satellite systems. ERS data, when used either alone or in conjunction with other data, are particularly useful in the following applications: oceanography, glaciology, meteorology, forestry, soils, agriculture and hydrology.

11. The principal instruments on board the satellites include (a) an Active Microwave Instrument (AMI), which comprises a synthetic aperture radar (SAR) and a wind scatterometer; (b) a radar altimeter (RA); (c) an along-track scanning radiometer (ATSR), which comprises an infrared radiometer (IRR) and a microwave sounder (MWS); (d) precise range and range-rate equipment (PRARE), presently functioning only on ERS-2; and (e) a laser retroreflector. In addition, the ERS-2 mission contains the global ozone monitoring experiment (GOME), which provides atmospheric chemistry measurements (ozone and other gases) and an improved ATSR instrument that includes three visible channels.

12. SAR permits the acquisition of all-weather images of ocean-, ice- and land-surfaces and it facilitates the monitoring of coastal zones, polar ice, sea state, geological features, vegetation, land surface processes and hydrology. It also allows the derivation of digital elevation models (topographic maps). In wave mode, SAR is used to measure ocean-wave spectra and wave direction, while in scatterometer mode, AMI is used to measure wind direction and speed at the ocean surface. The radar altimeter permits the measurement of wind

speed, wave height, sea-surface elevation, ice profile, land and ice topography, and sea-ice boundaries. ATSR is used to measure the surface temperatures of the sea, land and clouds. It is also used in the measurement of cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content. PRARE on ERS-2 provides precise corrections of altimeter measurements. The laser retroreflector is a passive optical device used as a target by ground-based laser ranging stations in order to determine the accurate position of the satellite.[1]

13. The participants from countries in the equatorial regions of Africa showed the greatest interest in the terrestrial applications of images obtained using the SAR instrument. In image mode, the SAR instrument acquires strips of images 100 km in width to the right of the satellite track. The ground spatial resolution is 25 m. It is different from optical sensors in that it operates within a frequency range, designated C-band, at a nominal frequency of 5.3 GHz with vertical transmission and vertical reception of radar signals (VV polarization) and a look angle of 23 degrees.

14. ERS-1 has a sun-synchronous, near polar, quasi-circular orbit with a mean altitude of 785 km and an inclination of 98.5 degrees. It has a 35-day repeat cycle with a re-visit period of 16-18 days. Its orbital cycle is 101 minutes. The data transmission rate for the SAR instrument is 105 megabits per second. On-board recorders cannot be used to store SAR data, which can only be transmitted to receiving stations when these are in sight. ERS-2 is similar in operation to ERS-1. Following the commissioning phase of ERS-2, the two satellites will operate in tandem with ERS-2 following ERS-1 at a separation time of 1 day. This time of separation is subject to change. It is planned to maintain the ground track between the two satellites at 50-600 metres in order to improve opportunities for interferometric applications.

B. Interpretation of European remote sensing satellite data for applications of national interest

15. Radar remote sensing from space has a number of advantages over airborne radar. Unlike spaceborne radar where the incidence angle changes very little, in airborne applications there is a large change in incidence angle across the image swath, which causes difficulty in distinguishing whether changes in backscatter are related simply to changes in incident angle or to changes in the geometry and/or the materials themselves. The look angle for the ERS satellites is 23 degrees (the local angle of incidence on the ground is slightly greater than this due to the curvature of Earth). At this look angle, radar backscatter is strongly influenced by topographic slope. Hence, surface features which give rise to changes in topography, e.g. geological lineaments which may indicate mineral occurrences, are more easily interpretable using spaceborne imagery. Nevertheless, effects such as radar shadowing, layover (relief displacement) and foreshortening can complicate the visual interpretation of imagery of areas of rugged terrain.

16. Radar backscatter is dominated by the geometrical and electrical properties of surface materials, a fact which must be taken into account during the interpretation of radar images. Materials of varying roughness - a factor which is dependent on the particular radar wavelength being used - reflect the radar signal in different ways. Rough surfaces cause diffuse reflections in all directions and a significant portion of the signal is returned to the sensor. Smooth surfaces result in specular reflection with practically all of the signal being reflected away from the sensor. Very high return signals occur when adjacent smooth surfaces form right angles, which cause a double reflection and hence high return signals to the sensor. This occurs naturally, for example, in the case of tree trunks standing in swampy, water-logged areas.

17. The electrical character of surface material, as indicated by its complex dielectric constant, is also critical in the interpretation of radar images. Radar reflectivity is considerably increased in the presence of water, which has a dielectric constant greater than 10 times that of dry materials. This characteristic makes radar imagery especially useful in differentiating areas of dry from moist soil and in the identification of vegetated zones often characterized by high humidity that would give rise to a strong radar response.

18. Radar reflection from vegetation is also influenced by the type of polarization. In general, like-polarized signals, such as the VV polarization of the ERS instruments, are better at penetrating vegetation than crossed-polarized signals. While ERS and Radarsat satellites operate in the C-band, JERS-1 operates in the longer L-band. Radar penetration of vegetation - forests and agricultural crops - is influenced by the wavelength of the signal. Shorter wavelengths may be scattered by the tree canopy, however, longer wavelengths tend to penetrate it and be reflected by the underlying soil. The use of radar images of multiple wavelengths from multiple space platforms (e.g. ERS/Radarsat, JERS-1, Shuttle Imaging Radar/Seasat) can therefore provide more information and allow for better differentiation in certain land-cover and forestry studies.

19. In general, through a knowledge of the interdependence of the factors which have a major influence on radar response (e.g. incidence angle, moisture content, surface roughness, geometry and slope orientation), ERS imagery corresponding to a single date can be interpreted for a variety of terrestrial applications. These applications can be placed in one or more of the following categories: (a) feature identification, (b) determination of the spatial extent of a feature of interest, (c) detection of change, e.g. deforestation, and (d) quantitative determination of biogeophysical parameters, e.g. soil-water content.

20. The interpretation of ERS imagery can be facilitated by digital enhancement procedures (filtering, colour coding etc.) that serve to highlight particular features of interest. Radar images are often characterized by speckle, which appears as a salt-and-pepper pattern. This effect is due to random constructive and destructive interference of radar waves that results in a random pattern of light and dark areas on the imagery. Speckle can be reduced by application of appropriate digital filtering or multi-look processing procedures. The reduction of speckle is a necessary precursor to computer classification of radar imagery as well as to visual interpretation since it tends to mask fine details.

21. In addition to the various possible enhancement of imagery from a single date, images from multiple dates can be exploited to yield new information, e.g. change detection. A single image from a given date may not be sufficient to differentiate several different crop types. However, two or more images acquired at different times during the growing season may allow differentiation of crop cover. In addition, colour composites of radar images of the same area taken at three different times can allow some differentiation of tree species and thereby avoid the difficulties of interpretation of tones and textures on a single image which may be due principally to variations in topography and not of tree species. Soils whose moisture content evolves differently during the year may be differentiated using multiple-date images.

22. In instances when both optical and radar satellite images are available, the two can be merged to exploit the complementarity that exists between the two data sets. Techniques for merging optical and radar data, such as the construction of colour composites and intensity-hue-saturation (IHS) transformations, can be employed to emphasize or de-emphasize surface features while retaining information from both data sets. Such merging operations must overcome difficulties of image co-registration, i.e. the accurate matching of common features appearing on both images when these are superimposed. For this reason, in areas of appreciable relief, a digital elevation model is used during registration to correct for relief displacements.

23. The technique of interferometry, by which the "phase" difference associated with a given pixel from two SAR images is analysed, allows for precise determination of elevation. The preparation of precise topographic maps from SAR images is therefore possible. Differential interferometry also allows for the monitoring of volcanic eruptions and earthquakes.

C. Data access and processing

24. Information on the availability of processed ERS data collected at the Libreville station and archived at the DLR facility at Oberpfaffenhofen, Germany, is readily available using a software program called DESC developed by ESA. The program allows interactive searching of a database to find and identify image frames

which correspond to a geographic region of interest. This database is periodically updated by ESA and distributed to registered users. Updates can also be obtained electronically via the Internet.

25. The high volumes of data associated with digital processing (e.g. geocoding, enhancements) of ERS images necessitate access to fairly powerful PC-based systems with software capable of processing and displaying 16-bit ERS images. In addition, the production of high-quality prints of the digitally enhanced images would require access to large-format printers. The high costs inherent in the acquisition of these items of equipment may put digital image processing of radar data out of the reach of some African institutions. However, the preparation of large-scale photographic prints of ERS images may be more cost-effective if it is initially left to service companies in Europe and elsewhere.

II. RECOMMENDATIONS OF THE WORKING GROUPS

26. Based on the potential usefulness of satellite radar data as presented during the training course, the participants identified a number of projects which could benefit from the radar data collected at the Libreville receiving station. Some of these projects are already ongoing and involve the institutions to which the participants are attached. The remainder are newly conceived project proposals. Summaries of the various projects are presented in tabular form in annex II. The tables regroup projects by theme, namely, (a) agriculture and forestry, (b) land use and landcover, and (c) mineral resources. The projects listed represent the output of three working groups, corresponding to each of the three application themes. These groups were constituted specifically to discuss national and regional development issues and to identify specific target activities which can benefit from the exploitation of ERS data. The working groups also made a number of recommendations which aim at enhancing the use of ERS data by countries within the region. These recommendations are aimed at all relevant entitites, including the United Nations, Governments and space agencies, whose timely interventions may serve to improve the present situation. The recommendations have been synthesized and are as follows:

(a) Participants should have access to more in-depth training on detailed radar image interpretation. In general, while a one-week training course is good for a general introduction to radar, a course lasting approximately three weeks is needed to develop the technical confidence needed to use the data on an operational basis;

(b) A follow-up training course should be organized to share operational experiences on applications of ERS data and to consolidate technical concepts introduced during the present course;

(c) Countries within the region should have access to the ERS images collected by the Libreville station;

(d) Cooperation between South-South and North-South in matters related to ERS data should be promoted and strengthened;

(e) Training should be given in Geographic Information Systems (GIS) technology and the integration of radar and other remote sensing data in GIS systems;

(f) Countries within the region should have access to technical assistance in matters related to the exploitation of radar images within an operational setting;

(g) National and regional institutions should be invited to participate in the demonstration studies of

27. There is as yet limited experience on the use of satellite radar images in tropical regions. For this reason, the operational usefulness of ERS data in African countries needs to be demonstrated. Necessarily, such a demonstration should involve African institutions and professionals who are knowledgeable of ground conditions and can attest to the usefulness and applicability of the radar data under their local conditions.

28. As illustrated in annex II, the problems which have already been encountered in existing projects or those that are envisaged in proposed ones concern the presence of heavy cloud cover on conventional optical satellite images. Thus, a principal need is adequate access to the radar images which have been collected by the ERS station at Libreville.

29. Only a few of the participants came from institutions which possessed the computer hardware and software needed for digital processing of voluminous ERS radar. Consequently, there was considerable discussion on ways in which to gain immediate access to the paper prints of digital images which would be suitably enhanced so as to highlight particular features of thematic interest, e.g. geology, land use and land cover, agriculture and forestry. In that regard, it appears that private companies in Europe which already have experience in the digital processing and enhancement of ERS data as well as in their photographic reproduction may be used to create large-scale photomaps. Such maps could easily be used at the present time by all of the countries represented at the training course. An eventual progression towards the digital processing and printing of ERS images is, however, highly desirable, particularly by participants from those national institutions which already have several years of experience in digital image analysis.

III. COURSE EVALUATION

30. Suggestions abstracted from the evaluation sheets filled in by the participants are as follows:

(a) Access to more detailed training (lasting at least 10 days) is highly desirable, in association with national or international entities experienced in the specific area of application;

(b) The course should devote more time for practical exercises;

(c) French documentation on ERS radar applications in all themes of interest should be made available;

(d) A wider distribution of information concerning training courses should be made available well ahead of their scheduling;

(e) Consideration should be given in order to avoid problems of distribution, to making direct contact with the national agencies or contact persons concerned, perhaps using electronic means, in addition to the normal official channels;

(f) The United Nations and ESA should maintain contact with the participants after the course in order to keep them abreast of developments in satellite radar technology;

(g) A follow-up meeting should be held in one or two years;

(h) Access should be given to training on digital analysis of radar images.

IV. PROPOSED FOLLOW-UP PLAN OF ACTION

31. The Office for Outer Space Affairs together with ESA propose to respond to the recommendations of the working groups and the various comments made during the course evaluation by undertaking the

(a) A number of projects will be selected from among those already proposed by the participants for possible assistance. In this regard, more detailed proposals than those elaborated during the course will be solicited from the participants in order to evaluate properly the relative merits of the various proposals and to facilitate the selection, on a competitive basis, of a number of projects worthy of support;

(b) Subsequently, arrangements will be made for supporting the selected projects within the framework of an assistance programme currently being developed jointly by the Office for Outer Space Affairs and ESA. As envisaged, this programme will provide limited support (e.g. training, access to satellite images and selected items of equipment needed for image interpretation) for ongoing activities;

(c) Expansion of the distribution of information related to the scheduling of the various training programmes and workshops organized each year by the Office for Outer Space Affairs will be made progressively to include selected national institutions whose activities may benefit from the application of space technology. Priority will be given to information distribution by electronic means (e.g. e-mail);

(d) Access to information pertaining to ERS applications will be improved. (Some action has already been taken by ESA in this regard. Specifically, the names of all course participants has been put on the ESA mailing list to receive the *Earth Observation Quarterly*. In addition, ESA has mailed copies of the DESC software program to all participants.);

(e) A follow-up advanced training course/seminar will be held involving participants who will have used ERS data from the Libreville station in an operational setting.

Notes

[1]European Space Agency, *Committee on Earth Observation Satellites: Coordination for the Next Decade*, 1995 CEOS Yearbook (United Kingdom, Smith System Engineering Limited, 1995) and European Space Agency, *ERS-1 User Handbook*, Louis Proud and Bruce Battrick, eds. (ESA SP-1148) (Noordwijke, Netherlands, 1992).

Annex I

PROGRAMME OF THE TRAINING COURSE

Time	*Subject*	*Speaker*
Monday, 15 May		
	Opening ceremony	
0930-1030	Addresses by the following:	
	• Representative of the United Nations Office for Outer Space Affairs	Hubert George
	• Resident Coordinator of UNDP	Toon Vissers
	• Representative of the European Space Agency	Karl Bergquist
	• Minister of Water and Forests, Post and Telecommunications and the Environment	Martin Fidèle Magnaga
	Basic concepts of radar remote sensing	
1130-1215	Remote sensing based on different regions of the electromagnetic spectrum	M. Fea, ESA
1215-1300	Theory and concepts of SAR	M. Fea, ESA
1430-1500	ERS: Space and ground segments	M. Fea, ESA
1500-1730	Practical exercises on satellite images	M. Fea, ESA
Tuesday, 16 May		
	Access to data and products	
0900-0945	Radar activities of GDTA	R. Nadal, GDTA
0945-1045	ERS: Data and products	M. Fea, ESA
1045-1130	Improvement of access to the information required for development: an initiative of the Office for Outer Space Affairs	H. George, OOSA
1130-1200	Access to and query of ERS databases: Demonstration of the DESC software	M. Fea, ESA

Time	*Subject*	*Speaker*
	Basic concepts of radar remote sensing (cont'd.)	
1200-1300	The complementarity between optical and radar data	R. Nadal, GDTA
1430-1530	Image quality, filtering, colour coding	M. Fea, ESA
1530-1730	Practical exercises on radar images	M. Fea, ESA
Wednesday, 17 May		
	Applications based on ERS radar data	
0900-0945	ERS data applied to problems of development in central Africa	P. Puyot-Lascassie (Scot Conseil)
0945-1130	Applications related to (a) land-use, (b) geology and mineral exploration, and (c) agriculture and forestry	M. Fea, ESA
1130-1300	A recent application of ERS data: radar interferometry	M. Fea, ESA
	Practical thematic exercises and group work on the analysis and the interpretation of ERS data within an African context	
1430-1630	Thematic exercises: the processing and interpretation of radar images	M. Fea, ESA
1630-1730	Group work on projects related to: • Land cover and land use • Geology and mineral exploration • Agriculture and forestry	
Thursday, 18 May		
0900-1100	Visit to the mobile ERS satellite receiving station	K. Reiniger, DLR
1100-1200	Operation of the ERS satellite receiving station	K. Reiniger, DLR
1200-1300	Group work (continued)	
1430-1730	Group work (continued)	
Friday, 19 May		
0900-1300	Group work (continued)	
1430-1730	Presentation of group projects	
	Course evaluation and closing ceremony	
1700-1730	Course evaluation	
1730-1800	Closing ceremony	

Annex II

PROPOSED PROJECTS

y in progress or for which funding is being sought – Agriculture and Forests

untry)	Objective	Present status	Difficulties	Needs
(Benin)	Rational use of land in rural areas	Project finalized; funding being sought	Access to satellite images	Technical support from ESA
(Burkina Faso)	Restoration of protected areas	Not specified	Insufficient photographic images	Acquisition of supplementary radar and optical satellite images
s: (Central African	Crop monitoring, land cover mapping	In progress (World Bank 1993-1998)	Significant cloud cover on SPOT images used for land use/land cover mapping	Access to paper prints of ERS radar images to complement SPOT images
esources: (Chad)	Crop monitoring using NOAA images Update information on natural resources	In progress In progress	None specified	Use radar images to complement existing sources of information
nt	Updating maps on land use and natural resources Assure the sustainable development of the GAMBA complex	Funding being sought In progress	Cloud cover on optical images Available IGN maps are out of date causing slow progress	Access to radar and optical satellite images Access to appropriate satellite imagery
n: (Gabon)	Map of forest production areas (5 million hectares)	Funding being sought from OIBT	Cloud cover on optical images (SPOT and LANDSAT)	Access to ERS images to complement existing information
al Resources: (Niger)	Creation of updated maps	About to start	Cloud cover in SPOT and LANDSAT images	Access to ERS images to complement existing data

ojects – Land use and land cover mapping

oject (Country)	Objective	Anticipated technical difficulties	Needs
nd cover mapping of es covering forested d areas: (Burkina	Integrated land planning and management; monitoring of migrations	Poor availability of optical images (cloud cover greater than 30 per cent during the rainy season)	Access to prints and digital satellite images; computers, software, training
sing and image f radar images:	Advanced research on radar image processing for regional and international applications related to littoral zones, hydrology, geology and geomorphology, human impacts	Heavy cloud cover in optical images of zones of interest	Access to a wide range of data including ERS satellite images
of lakes using remote had)	Mapping of lakes at 1:200,000 using SPOT and ERS images	Not specified	Technical assistance, equipment, training
mapping: (Congo)	Update 1:200,000 maps of forested zones (e.g. "Mayombe" forest) using ERS and SPOT images	Heavy cloud cover	Technical assistance, equipment, training, documentation
agement ng: (Gabon)	Monitoring the exploitation of forests Establish plans for each town	Heavy cloud cover	Access to ERS and SPOT data; training

jects – Mineral resources

ect	Objective	Anticipated technical difficulties	Needs
mineral resources s in the geographic d by the ERS ion at Libreville)	*Medium term* Preparation of geological maps *Long term* Preparation of thematic maps	Heavy cloud cover	Access to ERS data Documentation, collaboration with institutions experienced in geological applications; equipment for radar image interpretation, training Access to topographic applications of satellite radar data